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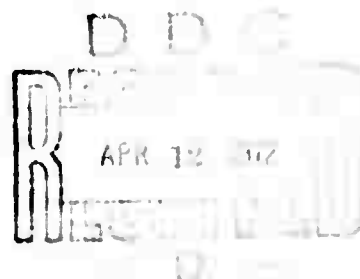
# A Documentation of the Mintz-Arakawa Two-Level Atmospheric General Circulation Model

W. L. Gates, E. S. Batten, A. B. Kahle and A. B. Nelson

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PREFACE

This documentation describes the two-level Mintz-Arakawa atmospheric general circulation model developed by Professors Mintz and Arakawa of the Department of Meteorology, University of California, Los Angeles. This is the first of a series of numerical models of the global circulation being used at Rand in a research program on the dynamics of climate. Through the selective alteration of the model's initial and boundary conditions, and of the model's physical and numerical treatment of atmospheric processes, it is planned that the sensitivity and response of the world's climates to either deliberate or inadvertent modification be explored. It is the purpose of the present documentation to facilitate those modifications of the model that may be required to simulate such climatic effects. This model, which was developed at UCLA with the support of the National Science Foundation, is undergoing continuing development, particularly with respect to the parameterization of convective heating and radiative transfer. The numerical solutions shown in this report are for illustrative purposes only and should not be used to judge the model's ability to simulate climate. Although every effort has been made to ensure the accuracy of the model description used here, the responsibility for any errors or misrepresentations rests solely with the authors.

The Rand research program on climate dynamics is sponsored by the Advanced Research Projects Agency, and is directed to the systematic exploration of the structure and stability of the earth's climate. Meteorological studies suggest that technologically feasible operations might trigger substantial changes in the climate over broad regions of the globe. Depending on their character, location, and scale, these changes might be both deleterious and irreversible. If such perturbations were to occur, the results might be seriously detrimental to the welfare of this country. So that we may react rationally and effectively to any such occurrences, it is essential that we: (1) evaluate all consequences of a variety of possible

occurrences that might modify the climate, (2) detect trends in the global circulation that presage changes in the climate, either natural or artificial, and (3) determine, if possible, means to counter potentially deleterious climatic changes. Our possession of this knowledge would make incautious experimentation unnecessary. The present Report is a technical contribution to this larger study of the effects on climate of environmental perturbations.



## SUMMARY

In this documentation the physical bases of the Mintz-Arakawa two-level atmospheric model are summarized, and the numerical procedures and computer program for its execution are presented in detail. The physics of the model is summarized, with particular attention given to the treatment of the moisture and heat sources, including the parameterization of convective processes, cloudiness, and radiation. The numerical approximations and finite-difference equations used in the model's numerical simulations are also given. Throughout the documentation the emphasis is on the specific details of the model in its present form, rather than on the derivation or justification of its present design.

To facilitate the use of this model, a complete listing of the code as written in FORTRAN language is given, together with a description of all constants and parameters used. A complete dictionary of FORTRAN variables, a dictionary of principal physical features, and a complete list of symbols are presented. To illustrate the model's performance, samples of its solutions for selected variables at a specific time are also given.

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The authors would like to acknowledge the permission given by Professors Yale Mintz and Akio Arakawa of the University of California, Los Angeles, to use their atmospheric general circulation model, and for their numerous comments and suggestions made during their review of a draft version of this Report. They would like also to thank Dr. A. Katayama, of the Meteorological Research Institute, Tokyo, for a number of suggestions that have clarified the program description, and Professor R. T. Williams of the Naval Postgraduate School for his assistance during the early stages of the preparation of the model's code description. An expression of thanks is also due our colleagues in the Rand/ARPA Climate Dynamics Program for their encouragement. Finally, we would like to acknowledge the capable and patient typing of the manuscript by Phyllis Davidson.

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## I. INTRODUCTION

One of the more widely known numerical models of the global atmospheric general circulation is that developed by Professors Mintz and Arakawa at the Department of Meteorology, UCLA. First formulated in the early 1960s, this model has undergone a series of modifications and improvements, and has been used in a number of simulations of the global climate and in tests of atmospheric predictability. Although it addresses the primary dynamical and thermal variables at only two tropospheric levels, the model is relatively sophisticated in its treatment of the physics of large-scale atmospheric motion, and the method of numerical solution is relatively complex.

It is the purpose of this Report to describe the model from a user's viewpoint, in order to facilitate its actual use in a program of climatic simulation. Although some description of the model's basic equations is necessary, it is not our present purpose to present their derivation nor to discuss the justification of the model's many physical parameterizations and numerical procedures. Instead, we have attempted to set forth several aspects of the model: its physical basis, its numerical formulation and solution, its computer code, and its typical results. These aspects are related to one another by the provision of a dictionary of selected terms and a list of physical and FORTRAN symbols. The description of the model's physics, given in Chapter II, is intended to present the basic differential equations and physical constants; the corresponding difference equations and other numerical approximations used in the program are presented in Chapter III. This is followed by a summary of the program's operating characteristics in Chapter IV, together with some typical results for selected variables, and by Chapter V, which presents a physics dictionary giving a brief summary of the treatment of certain variables and effects. As a supplement to the preceding chapters, a comprehensive list of symbols is given in Chapter VI. Finally, the model's integration and output map-routine codes as written in FORTRAN are presented *in extenso* in Chapter VII, followed by a FORTRAN dictionary in Chapter VIII, whose purpose is to permit ready interpretation of

specific portions of the program. It is hoped that this documentation will answer the question, "Just how are the circulation simulations made?"

A previous description of the model (in one of its earlier versions) was given by Mintz (1965, 1968), and has been supplemented by Arakawa (1970). Further details of the treatment of convection and radiation were given by Arakawa, Katayama, and Mintz (1969). An extended description of the basic model and the computational procedures used was prepared by Langlois and Kwok (1969). This latter publication has been of particular use in the preparation of the present documentation, although the present version of the model differs slightly from the version described by them. In one form or another the Mintz-Arakawa two-level model was applied to the estimation of atmospheric predictability by Charney (1966) and Jastrow and Halem (1970), and was applied to the simulation of the circulation of the Martian atmosphere by Leovy and Mintz (1969). The present version of the model is being used in a program of experimentation on the dynamics of climate at Rand, and will form the basis of future model changes and extensions.

## II. MODEL DESCRIPTION -- PHYSICS

In this chapter the physical and dynamical basis of the Mintz-Arakawa two-level general circulation model is presented, together with a summary of the basic differential equations and boundary conditions. Particular attention has been given to the preparation of a summary of the various physical approximations in the model's treatment of radiation, moisture, and convection.

### A. NOTATION AND VERTICAL LAYERING

In the first instance the present model is for the troposphere only, and divides the atmosphere beneath an assumed isobaric tropopause into two layers, as sketched in Fig. 2.1. At the center of each layer are the reference levels (1 and 3) at which the basic variables of the model are carried. At the interface between the layers (level 2), as well as at the tropopause and earth's surface, certain additional variables and conditions are specified. For convenience, the atmosphere is divided in the vertical according to mass (or pressure), and the dimensionless vertical coordinate,  $\sigma$ , is introduced

$$\sigma \equiv \frac{p - p_T}{p_s - p_T} \quad (2.1)$$

where  $p$  is the pressure,  $p_T$  the (constant) tropopause pressure, and  $p_s$  the (variable) pressure at the earth's surface. The levels 1, 2, and 3 are defined as those for  $\sigma = 1/4$ ,  $1/2$ , and  $3/4$ , respectively, with the tropopause corresponding to  $\sigma = 0$  and the surface always given by  $\sigma = 1$ . Thus, if the surface pressure is approximately 1000 mb and the tropopause is assumed to be at 200 mb, the levels 1 and 3 correspond approximately to the 400-mb and 800-mb levels, respectively.

Although a comprehensive list of symbols appears later in this report (see Chapter VI), it is convenient to introduce the more common variables at this point. Anticipating the use of spherical coordinates, the independent variables are:



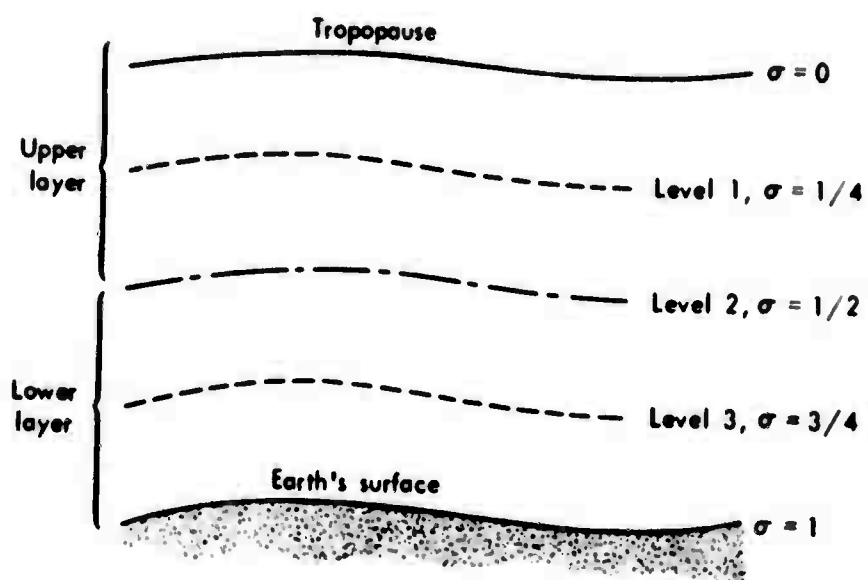


Fig. 2.1 -- Schematic representation of the model's vertical structure.

- $\varphi$  = latitude, positive northward from the equator
- $\lambda$  = longitude, positive eastward from Greenwich
- $\sigma$  = dimensionless vertical coordinate,  $0 \leq \sigma \leq 1$ , increasing downward
- $t$  = time

The primary dependent (prognostic) variables are:

- $\vec{V} = (u, v)$ , horizontal vector velocity
- $T$  = temperature
- $\pi = p_s - p_T$ , surface pressure parameter
- $q$  = mixing ratio

The other dependent (diagnostic) variables are:

- $\phi$  = geopotential
- $\alpha$  = specific volume
- $p$  = pressure
- $\dot{\sigma} = \frac{d\sigma}{dt}$ , sigma vertical-velocity measure

The forcing terms are:

- $\vec{F}$  = horizontal vector frictional force per unit mass
- $\dot{H}$  = diabatic heating rate per unit mass
- $\dot{Q}$  = rate of moisture addition per unit mass

The basic physical constants are:

- $f = 2\Omega \sin \varphi$ , Coriolis parameter
- $\Omega$  = earth's rotation rate
- $a$  = earth's radius
- $\vec{k}$  = vertical unit vector
- $c_p$  = specific heat (for dry air) at constant pressure
- $R$  = specific gas constant (for dry air)
- $g$  = acceleration of gravity

## B. DIFFERENTIAL EQUATIONS

The vector equation of horizontal motion (in  $\sigma$  coordinates) may be written

$$\begin{aligned} \frac{\partial}{\partial t} (\pi \vec{V}) + (\nabla \cdot \pi \vec{V}) \vec{V} + \frac{\partial}{\partial \sigma} (\pi \vec{V} \dot{\sigma}) + f \vec{k} \times \pi \vec{V} \\ + \pi \nabla \phi + \sigma \pi \alpha \nabla \pi = \pi \vec{F} \end{aligned} \quad (2.2)$$

where

$$\nabla \cdot \vec{A} = \frac{1}{a \cos \varphi} \left[ \frac{\partial A_{\lambda}}{\partial \lambda} + \frac{\partial}{\partial \varphi} (A_{\varphi} \cos \varphi) \right] \quad (2.3)$$

for a vector  $\vec{A} = (A_{\lambda}, A_{\varphi})$ .

The thermodynamic energy equation (in  $\sigma$  coordinates) is written

$$\begin{aligned} \frac{\partial}{\partial t} (\pi c_p T) + \nabla \cdot (\pi c_p T \vec{V}) + \frac{\partial}{\partial \sigma} (\pi c_p T \dot{\sigma}) \\ - \pi \alpha \left( \sigma \frac{\partial \pi}{\partial t} + \sigma \vec{V} \cdot \nabla \pi + \pi \dot{\sigma} \right) = \pi \dot{H} \end{aligned} \quad (2.4)$$

The mass continuity equation is

$$\frac{\partial \pi}{\partial t} + \nabla \cdot (\pi \vec{V}) + \frac{\partial}{\partial \sigma} (\pi \dot{\sigma}) = 0 \quad (2.5)$$

The moisture continuity equation is

$$\frac{\partial}{\partial t} (\pi q) + \nabla \cdot (\pi q \vec{V}) + \frac{\partial}{\partial \sigma} (\pi q \dot{\sigma}) = \pi \dot{Q} \quad (2.6)$$

The equations (2.2) and (2.4) to (2.6) are the prognostic equations for the dependent variables  $\vec{V}$ ,  $T$ ,  $\pi$ , and  $q$ . The specification of the frictional force ( $\vec{F}$ ), the heating rate ( $\dot{H}$ ), and the moisture-addition

rate ( $\dot{Q}$ ), or the right-hand sides of these equations is considered in subsequent sections. Supplementing these equations are the diagnostic equation of state,

$$\alpha = RT/p \quad (2.7)$$

and the hydrostatic equation,

$$\frac{\partial \phi}{\partial \sigma} + \pi \alpha = 0 \quad (2.8)$$

These complete the dynamical system in  $\sigma$  coordinates, with  $\sigma$  itself given by  $\sigma = (p - p_T)/\pi$ , where  $p_T$  is a constant (tropopause) pressure.

### C. BOUNDARY CONDITIONS

Accompanying the dynamical system, Eqs. (2.2) to (2.8), are physical boundary conditions at only the earth's surface and the tropopause, as there are no lateral boundaries in the  $\sigma$  system for the global atmosphere. At the earth's surface we require zero (air) mass flux normal to the earth's surface and either a zero heat flux or a specified surface temperature, depending upon the surface character. Thus, we write at the earth's surface:

$$\left. \begin{array}{l} \dot{\sigma} = 0 \\ \phi = \phi_s(\lambda, \varphi) \\ F_H = 0 \end{array} \right\} \quad \text{at } \sigma = 1 \text{ over land} \quad (2.8a)$$

$$\left. \begin{array}{l} \dot{\sigma} = 0 \\ \phi = 0 \\ T = T_s(\lambda, \varphi) \end{array} \right\} \quad \text{at } \sigma = 1 \text{ over ocean} \quad (2.8b)$$

Here  $\phi_4(\lambda, \varphi)$  denotes the fixed distribution of the geopotential of the earth's land (or ice) surface,  $F_H$  is the vertical heat flux at the surface, and  $T_s(\lambda, \varphi)$  the fixed distribution of the sea-surface temperature.

At the assumed isobaric tropopause  $p = p_T$  we require the free-surface condition  $dp/dt = 0$ , or

$$\dot{\sigma} = 0, \quad \text{at } \sigma = 0 \quad (2.8c)$$

Although they are not strictly boundary conditions, we may regard the specification of the surface drag coefficient which contributes to the horizontal frictional force,  $\vec{F}$ , in Eq. (2.2) as fixing the vertical momentum transfer at the surface, and similarly regard the specification of the surface evaporation (minus the surface precipitation and runoff) as determining the moisture available for the source  $\dot{Q}$  in Eq. (2.6). The determination of these transfers in terms of the model is described below. We might also regard the solar radiation at the top of the atmospheric model at  $\sigma = 0$  as a boundary condition. Here this flux is assumed to be given by the solar constant, modified as described below by the eccentricity of the earth's orbit and by the zenith angle of the sun.

#### D. VERTICALLY DIFFERENCED EQUATIONS

##### 1. Vector Form

As an introduction to the presentation of the complete difference equations (including the horizontal and time finite-difference forms), the model's dynamical equations are here first stated in terms of the variables at specific model levels (which statement constitutes the vertical differencing in  $\sigma$  coordinates), and then given in terms of the horizontal (rectangular) map coordinates actually used in the computations. The dependent variables are computed at the several levels as shown below:

Table 2.1  
DISPOSITION OF THE DEPENDENT VARIABLES

Level	$\sigma$	$\delta$	$\phi$	$p$	$T$	$\vec{V}$	$q$
0 .....	0	0	...	$p_T$	...	...	...
1 -----	$\frac{1}{4}$	...	$\phi_1$	$p_1$	$T_1$	$\vec{V}_1$	0
2 .....	$\frac{1}{2}$	$\dot{\sigma}_2$	...	$p_2$	...	...	...
3 -----	$\frac{3}{4}$	...	$\phi_3$	$p_3$	$T_3$	$\vec{V}_3$	$q_3$
4 ..... (surface)	1	0	...	$p_T + \pi$	...	...	...

We note that the mixing ratio,  $q$ , is carried only at level 3, and that the surface pressure is computed by means of  $\pi$ . At the midlevel 2, only the  $\sigma$  vertical velocity  $\dot{\sigma}_2$  is independently computed, although it is sometime useful to regard the wind and temperature at level 2 in terms of values interpolated between levels 1 and 3.

The equation of horizontal motion, Eq. (2.2), is now written for levels 1 and 3 (with corresponding subscripts) as

$$\begin{aligned} \frac{\partial}{\partial t} (\pi \vec{V}_1) + (\nabla \cdot \pi \vec{V}_1) \vec{V}_1 + \pi \dot{\sigma}_2 (\vec{V}_1 + \vec{V}_3) + \pi f \vec{k} \times \vec{V}_1 \\ + \pi \nabla \phi_1 + \sigma_1 \pi \alpha_1 \nabla \pi = \pi \vec{F}_1 \end{aligned} \quad (2.9)$$

$$\begin{aligned} \frac{\partial}{\partial t} (\pi \vec{v}_3) + (\nabla \cdot \pi \vec{v}_3) \vec{v}_3 - \pi \dot{\sigma}_2 (\vec{v}_1 + \vec{v}_3) + \pi f \vec{k} \times \vec{v}_3 \\ + \pi \nabla \phi_3 + \sigma_3 \pi \alpha_3 \nabla \pi = \pi \vec{F}_3 \end{aligned} \quad (2.10)$$

where vertical finite differences between  $\sigma = 0$  and  $\sigma = 1/2$  and between  $\sigma = 1/2$  and  $\sigma = 1$  have been taken, and the conditions  $\dot{\sigma} \equiv 0$  at  $\sigma = 0, 1$  and  $\vec{v}_2 = 1/2(\vec{v}_1 + \vec{v}_3)$  used.

The thermal energy equation (2.4) may be similarly written for levels 1 and 3 as

$$\begin{aligned} \frac{\partial}{\partial t} (\pi T_1) + \nabla \cdot (\pi T_1 \vec{v}_1) + \left( \frac{p_1}{p_0} \right)^\kappa \pi \dot{\sigma}_2 (\theta_1 + \theta_3) \\ - \frac{\pi \alpha_1 \sigma_1}{c_p} \left( \frac{\partial \pi}{\partial t} + \vec{v}_1 \cdot \nabla \pi \right) = \frac{\pi \dot{H}_1}{c_p} \end{aligned} \quad (2.11)$$

$$\begin{aligned} \frac{\partial}{\partial t} (\pi T_3) + \nabla \cdot (\pi T_3 \vec{v}_3) - \left( \frac{p_3}{p_0} \right)^\kappa \pi \dot{\sigma}_2 (\theta_1 + \theta_3) \\ - \frac{\pi \alpha_3 \sigma_3}{c_p} \left( \frac{\partial \pi}{\partial t} + \vec{v}_3 \cdot \nabla \pi \right) = \frac{\pi \dot{H}_3}{c_p} \end{aligned} \quad (2.12)$$

where the condition  $\theta_2 = 1/2(\theta_1 + \theta_3)$  has been used with the potential temperature,  $\theta$ , given by

$$\theta = T(p_0/p)^\kappa$$

with  $p_0 = 1000$  mb, a reference pressure, and  $\kappa = R/c_p = 0.286$ .

Manipulation of the mass continuity equation (2.5) applied at levels 1 and 3 with the conditions  $\dot{\sigma} = 0$  at  $\sigma = 0, 1$  leads to the relations

$$\frac{\partial \pi}{\partial t} = - \frac{1}{2} \nabla \cdot [\pi (\vec{v}_1 + \vec{v}_3)] \quad (2.13)$$

$$\dot{\sigma}_2 = -\frac{1}{4\pi} \nabla \cdot [\pi(\vec{V}_1 - \vec{V}_3)] \quad (2.14)$$

for the prediction of the surface pressure and the computation of the midtropospheric vertical motion field.

The moisture continuity equation (2.6) is applied only at the (lower) level 3, giving

$$\frac{\partial}{\partial t} (\pi q_3) + \nabla \cdot \left[ \pi q_3 \left( \frac{5}{4} \vec{V}_3 - \frac{1}{4} \vec{V}_1 \right) \right] = 2g(E - C) \quad (2.15)$$

where the conditions  $\dot{\sigma} = 0$  at  $\sigma = 1$  and  $q = 0$  at  $\sigma = 1/2$  have been used, and the wind at level 3 ( $\sigma = 3/4$ ) is replaced by a wind at  $\sigma = 7/8$  found by linear extrapolation from  $\vec{V}_1$  and  $\vec{V}_3$ . The moisture source term,  $2g(E - C)$ , represents the net rate of vapor addition as a result of the evaporation rate,  $E$ , and condensation rate,  $C$ , into the air column of unit cross section between  $\sigma = 1$  and  $\sigma = 1/2$ .

The hydrostatic equation (2.8) is integrated from the surface to the levels 1 and 3, yielding the relations

$$\phi_1 = \phi_4 + \frac{1}{2} c_p \theta_2 \left[ \left( \frac{p_3}{p_0} \right)^\kappa - \left( \frac{p_1}{p_0} \right)^\kappa \right] + \frac{\pi}{2} (\sigma_3 a_3 + \sigma_1 a_1) \quad (2.16)$$

$$\phi_3 = \phi_4 - \frac{1}{2} c_p \theta_2 \left[ \left( \frac{p_3}{p_0} \right)^\kappa - \left( \frac{p_1}{p_0} \right)^\kappa \right] + \frac{\pi}{2} (\sigma_3 a_3 + \sigma_1 a_1) \quad (2.17)$$

where  $\phi_4$  is the (fixed) geopotential of the earth's surface, and where  $\theta$  has been assumed linear in  $p^\kappa$  space from  $\sigma_1 = 1/4$  to the ground  $\sigma = 1$ .

## 2. Rectangular (Map) Coordinates

As a final transformation prior to the consideration of the difference equations used in the computations, it is convenient to present the vertically differenced equations (2.9) to (2.17) in terms of



the rectangular (or map) coordinates  $x$  and  $y$ . The grid-scale distances  $m$  and  $n$ , defined as

$$m = a \Delta \lambda \cos \varphi \quad (2.18)$$

$$n = a \Delta \varphi \quad (2.19)$$

represent the longitudinal and latitudinal distances between grid points separated by  $\Delta \lambda$  and  $\Delta \varphi$ , respectively. The dimensionless map coordinates  $x$  and  $y$  may then be defined as

$$x = m^{-1} a \Delta \lambda \cos \varphi \quad (2.20)$$

$$y = n^{-1} a \Delta \varphi \quad (2.21)$$

so that a rectangular grid-point array is generated with unit distance between points. The reciprocals  $m^{-1}$  and  $n^{-1}$  are the conventional map-scale or magnification factors.

We also introduce the new area-weighted variables

$$\Pi = mn\pi \quad (2.22)$$

$$\dot{S} = 2mn\pi \dot{\sigma}_2 \quad (2.23)$$

$$F = mnf - u \frac{dm}{dy} \quad (2.24)$$

and the weighted mass fluxes

$$u^* = n\pi u \quad (2.25)$$

$$v^* = m\pi v \quad (2.26)$$

at both levels 1 and 3.

Upon multiplication by  $mn$ , the equations of motion, Eqs. (2.9) and (2.10), may thus be written:

$$\begin{aligned} \frac{\partial}{\partial t} (\Pi u_1) + \frac{\partial}{\partial x} (u_1^* u_1) + \frac{\partial}{\partial y} (v_1^* u_1) + \dot{s} \left( \frac{u_1 + u_3}{2} \right) \\ + n \left( \pi \frac{\partial \phi_1}{\partial x} + \sigma_1 \pi \alpha_1 \frac{\partial \pi}{\partial x} \right) - F \pi v_1 = \Pi F_1^x \end{aligned} \quad (2.27)$$

$$\begin{aligned} \frac{\partial}{\partial t} (\Pi v_1) + \frac{\partial}{\partial x} (u_1^* v_1) + \frac{\partial}{\partial y} (v_1^* v_1) + \dot{s} \left( \frac{v_1 + v_3}{2} \right) \\ + m \left( \pi \frac{\partial \phi_1}{\partial y} + \sigma_1 \pi \alpha_1 \frac{\partial \pi}{\partial y} \right) + F \pi u_1 = \Pi F_1^y \end{aligned} \quad (2.28)$$

$$\begin{aligned} \frac{\partial}{\partial t} (\Pi u_3) + \frac{\partial}{\partial x} (u_3^* u_3) + \frac{\partial}{\partial y} (v_3^* u_3) - \dot{s} \left( \frac{u_1 + u_3}{2} \right) \\ + n \left( \pi \frac{\partial \phi_3}{\partial x} + \sigma_3 \pi \alpha_3 \frac{\partial \pi}{\partial x} \right) - F \pi v_3 = \Pi F_3^x \end{aligned} \quad (2.29)$$

$$\begin{aligned} \frac{\partial}{\partial t} (\Pi v_3) + \frac{\partial}{\partial x} (u_3^* v_3) + \frac{\partial}{\partial y} (v_3^* v_3) - \dot{s} \left( \frac{v_1 + v_3}{2} \right) \\ + m \left( \pi \frac{\partial \phi_3}{\partial y} + \sigma_3 \pi \alpha_3 \frac{\partial \pi}{\partial y} \right) + F \pi u_3 = \Pi F_3^y \end{aligned} \quad (2.30)$$

where the frictional force  $\vec{F} = (F^x, F^y)$  at levels 1 or 3.

The thermodynamic equations (2.11) and (2.12) may be similarly written as

$$\begin{aligned} \frac{\partial}{\partial t} (\Pi T_1) + \frac{\partial}{\partial x} (u_1^* T_1) + \frac{\partial}{\partial y} (v_1^* T_1) + \left( \frac{p_1}{p_0} \right)^{\kappa} \left( \frac{\theta_1 + \theta_3}{2} \right) \dot{s} \\ - \frac{\sigma_1 \alpha_1}{c_p} \left( \pi \frac{\partial \pi}{\partial t} + u_1^* \frac{\partial \pi}{\partial x} + v_1^* \frac{\partial \pi}{\partial y} \right) = \frac{\Pi \dot{H}_1}{c_p} \end{aligned} \quad (2.31)$$

$$\begin{aligned} \frac{\partial}{\partial t} (\Pi T_3) + \frac{\partial}{\partial x} (u_3^* T_3) + \frac{\partial}{\partial y} (v_3^* T_3) - \left( \frac{p_3}{p_0} \right)^{\kappa} \left( \frac{\theta_1 + \theta_3}{2} \right) \dot{s} \\ - \frac{\sigma_3 \alpha_3}{c_p} \left( \pi \frac{\partial \Pi}{\partial t} + u_3^* \frac{\partial \pi}{\partial x} + v_3^* \frac{\partial \pi}{\partial y} \right) = \frac{\Pi \dot{H}_3}{c_p} \end{aligned} \quad (2.32)$$

The mass and moisture continuity equations (2.13) to (2.15) may also now be written as

$$\frac{\partial \Pi}{\partial t} = - \frac{1}{2} \left[ \frac{\partial}{\partial x} (u_1^* + u_3^*) + \frac{\partial}{\partial y} (v_1^* + v_3^*) \right] \quad (2.33)$$

$$\dot{s} = \frac{1}{2} \left[ \frac{\partial}{\partial x} (u_3^* - u_1^*) + \frac{\partial}{\partial y} (v_3^* - v_1^*) \right] \quad (2.34)$$

$$\begin{aligned} \frac{\partial}{\partial t} (\Pi q_3) + \frac{\partial}{\partial x} \left[ q_3 \left( \frac{5}{4} u_3^* - \frac{1}{4} u_1^* \right) \right] \\ + \frac{\partial}{\partial y} \left[ q_3 \left( \frac{5}{4} v_3^* - \frac{1}{4} v_1^* \right) \right] = \frac{2 \Pi g}{\pi} (E - C) \end{aligned} \quad (2.35)$$

Equations (2.27) to (2.35), together with (2.16) and (2.17), constitute the final dynamical statement of the model in vertically differenced form. The introduction of time and horizontal spatial finite differences is considered in the following sections.

#### E. FRICTION TERMS

The frictional terms  $\vec{F}_1$  and  $\vec{F}_3$  in the equations of horizontal motion (2.9) and (2.10) are given by relations of the form

$$\vec{F}_1 = -\nu \left( \frac{\partial \vec{V}}{\partial z} \right)_2 \cdot \frac{2g}{\pi} = -\nu \left( \frac{\vec{V}_1 - \vec{V}_3}{z_1 - z_3} \right) \frac{2g}{\pi} \quad (2.36)$$

$$\vec{F}_3 = -\vec{F}_1 - C_D \rho_4 \vec{V}_s (|\vec{V}_s| + G) \frac{2g}{\pi} \quad (2.37)$$

where  $\mu$  is an empirical coefficient for the vertical shear stress, and the factor  $2g/\pi$  represents the mass per unit area in each of the two model layers. Here  $z_1 - z_3$  is the height difference between the levels 1 and 3,  $C_D$  is the surface drag coefficient,  $\rho_4$  the surface air density,  $\vec{V}_s$  a measure of the surface wind ( $= 0.7 \vec{V}_4$ , with  $\vec{V}_4$  an extrapolated wind at level 4), and  $G$  an empirical correction for gustiness.

The frictional force  $\vec{F}_1$  thus represents the internal downward transfer of momentum between the levels due to the vertical shear of the horizontal wind, whereas the force  $\vec{F}_3$  also includes the effects of surface skin friction.

#### F. MOISTURE, CONVECTION, AND CLOUDS

The purpose of this section is to describe the physics of the hydrologic cycle used in the model and to develop the expressions used to evaluate the moisture-source term,  $2 \frac{\pi g}{\pi} (E - C)$ , on the right-hand side of the moisture-balance equation for the atmosphere [Eq. (2.35)]. The moisture source for the atmosphere is evaporation from the surface,  $E$ , and the moisture sink is precipitation,  $C$ . All the moisture condensed in the model atmosphere is assumed to fall to the surface as precipitation. Thus the moisture sink for the atmosphere,  $C$ , is specified by large-scale, convective, and surface condensation. The variables specifying the amount of moisture in the atmosphere and in the ground are  $q_3$ , the lower-level mixing ratio, and  $GW$ , the ground-wetness parameter. While  $q_3$  is determined in part by horizontal advection and is thus modified every time step,  $GW$ ,  $E$ ,  $C$ , and that part of the change of  $q_3$  due to  $E$  and  $C$  are computed every fifth time step (see Chapter III, Section A).

Clearly, the amount of evaporation, condensation, and convection depend on the thermal state of the atmosphere, which is in turn a function of the exchange of heat taking place during these processes. Instead of obtaining a simultaneous solution for the moisture and thermal states of the atmosphere, the model evaluates the evaporation and the components of the condensation in a sequence. At each step

of the sequence the thermal state of the atmosphere is modified, and the new values of temperature are used in the next step.

In the following subsections each process is discussed in the sequence in which it is evaluated in the FORTRAN program. First, the temperature lapse rate between  $\sigma = 3/4$  and  $\sigma = 1/4$  is adjusted to the dry-adiabatic lapse rate if it is found to be dry-adiabatically unstable; this convective adjustment is discussed in Subsection F.1. Second, if the air is supersaturated at  $\sigma = 3/4$ , large-scale condensation occurs and the temperature and mixing ratios at  $\sigma = 3/4$  are adjusted (see Subsection F.2). Third, the temperature lapse rates between levels and the humidity are tested to determine the existence of moist convective instability. If there is instability, convective condensation occurs and the temperatures and mixing ratios are adjusted according to the three types of convection permitted:

- (a) Middle-level convection, which occurs if the layer between  $\sigma = 3/4$  and  $\sigma = 1/4$  is unstable (for moist convection).
- (b) Penetrating convection, which occurs if the layer from  $\sigma = 3/4$  to  $\sigma = 1/4$  is stable but the layer from the surface to  $\sigma = 3/4$  is unstable and, in the mean, unstable from the surface to  $\sigma = 1/4$ .
- (c) Low-level convection, which occurs if the atmosphere is unstable only between the surface and  $\sigma = 3/4$ .

To determine the existence of convection types (b) and (c), one needs the temperature and mixing ratios at the top of the surface boundary layer. All three forms of convective condensation and the physics of the boundary layer are discussed in Subsection F.3. Fourth, the quantities needed to evaluate the evaporation from the surface are discussed in Subsection F.4, and the moisture balance at the surface and in the atmosphere is discussed in Subsection F.5.

The final two subsections are devoted to parameters which are related to the moisture content of the atmosphere and are used in the radiation balance calculation in Section G. In Subsection F.6, the cloud types and cloud amounts produced by the various forms of condensation are discussed, and in Subsection F.7, equations for the effective water-vapor content of the atmosphere are derived.

### 1. Convective Adjustment

If, as a result of the changes due to advection, the atmosphere is found to be dry-adiabatically unstable ( $\theta_1 \leq \theta_3$ ) at the beginning of the heating and moisture-balance calculations, then a "convective adjustment" is made. This consists of setting both  $\theta_1$  and  $\theta_3$  equal to an average  $\bar{\theta}$ , which is calculated from

$$\bar{\theta} = \bar{T} \left[ \frac{1}{2} (p_1^\kappa + p_3^\kappa) \right]^{-1}$$

assuming that

$$\bar{T} = \frac{1}{2} (T_1 + T_3)$$

Thus, the convective adjustment consists of setting

$$\frac{\theta_1}{p_o^\kappa} = \frac{\theta_3}{p_o^\kappa} = \frac{\theta_2}{p_o^\kappa} = \frac{T_1 + T_3}{p_1^\kappa + p_3^\kappa} \quad (2.38)$$

from which the temperatures are accordingly recalculated as

$$\begin{aligned} T_1 &= \frac{\theta_1}{p_o^\kappa} p_3^\kappa \\ T_3 &= \frac{\theta_3}{p_o^\kappa} p_3^\kappa \end{aligned} \quad (2.39)$$

After this convective adjustment, the model proceeds as usual to the moisture and convection calculations.

### 2. Large-Scale Condensation

Large-scale condensation occurs if the lower-level grid cell is supersaturated at the beginning of the moisture-balance calculation.

The saturation mixing ratio is given by

$$q_s(T) = \frac{M_w}{M_d} \frac{e_s(T)}{p - e_s(T)} \quad (2.40)$$

where  $M_w$  and  $M_d$  are the mean molecular weights of water vapor and dry air, respectively ( $M_w/M_d = 0.622$ ), and where the saturation vapor pressure is given by the equation

$$e_s(T) = e_o \exp(A_e - B_e/T) \quad (2.41)$$

with  $e_o = 1$  mb,  $A_e = 21.656$ , and  $B_e = 5418$  deg K.

If it is then determined that  $q_3 > q_s(T_3)$  as a result of the computed solution of the moisture continuity equation (2.35), large-scale condensation is allowed to occur. This condensation will remove moisture from the atmosphere and will also warm the atmosphere by releasing latent heat, with the warming in turn modifying the saturation mixing ratio  $q_s(T_3)$ . The condensation proceeds until  $q_3 = q_s(T)$  at the new (warmed) temperature. If the original temperature and mixing ratio at level 3 are written as  $T_o$  and  $q_o$ , the new temperature  $T$  satisfies

$$c_p(T - T_o) = L[q_o - q_s(T)] \quad (2.42)$$

In view of the dependence of  $q_s$  on  $T$ , as given by Eqs. (2.40) and (2.41), we seek the approximate value of  $T$  when

$$F(T) = T - T_o + \left(\frac{L}{c_p}\right)[q_s(T) - q_o] = 0 \quad (2.43)$$

Using the Newton-Raphson method, the first-order approximation of  $T$  becomes

$$T \approx T_o - \frac{F(T_o)}{F'(T_o)} \quad (2.44)$$

where

$$F(T_o) = - \frac{L}{c_p} [q_o - q_s(T_o)] \quad (2.45)$$

and

$$F'(T_o) = \frac{dF}{dT}(T_o) = 1 + \frac{L}{c_p} q_s(T_o) \frac{B_e}{T_o^2} \left[ 1 + \frac{M_d}{M_w} q_s(T_o) \right] \quad (2.46)$$

Substituting Eqs. (2.45) and (2.46) into (2.44) and neglecting  $(M_d/M_w)q_s(T_o)$  in comparison with 1, the change in temperature at level 3 as a result of large-scale condensation becomes

$$(\Delta T_3)_{LS} = T - T_o = \frac{\frac{L}{c_p} [q_o - q_s(T_o)]}{1 + \frac{L}{c_p} q_s(T_o) \frac{B_e}{T_o^2}} \quad (2.47)$$

The change in moisture content due to this large-scale condensation is found from

$$(\Delta q_3)_{LS} = \frac{c_p}{L} (T_3)_{LS} \quad (2.48)$$

and the new  $q_3$  is given by

$$q_3 = q_{3o} - (\Delta q_3)_{LS} \quad (2.49)$$

Since the amount of precipitation is assumed to be equal to the condensation, the large-scale precipitation rate becomes

$$P_{LS} = (\pi/2g\omega)(\Delta q_3)_{LS} \quad (2.50)$$



where  $(\pi/2g)/\rho_w$  is a conversion factor used to obtain the precipitation rate from the condensation rate (see Chapter IV, Large-Scale Precipitation Rate: Map 9). Finally, the large-scale condensation produces type-2 clouds (see Subsection F.6).

### 3. Convective Condensation

To determine the possibility of convection, suitable stability criteria must first be defined. The equivalent potential temperature, defined as

$$\theta_E = \theta_d \exp\left(\frac{Lq}{c_p T}\right) \quad (2.51)$$

where

$$\theta_d = T \left( \frac{p_o}{p - e} \right)^\kappa \quad (2.52)$$

is conservative in both unsaturated-adiabatic and saturated-adiabatic processes. A more convenient parameter for our purposes is given by the approximation

$$\frac{c_p T}{\theta_e} d\theta_E \approx dh \quad (2.53)$$

Here

$$h = c_p T + gz + Lq \quad (2.54)$$

shall be referred to as the static energy; it is the sum of the enthalpy, the potential energy, and the latent energy of a parcel of air. The static energy is very nearly conservative in both unsaturated and saturated adiabatic processes, and thus can be used in the analysis of convective phenomena. For example, following the argument

of Arakawa et al. (1969), if we assume that the air in the clouds at level 1 is saturated, then the static energy in the cloud at level 1 becomes

$$h_c = c_p T_{cl} + gz_1 + Lq_s(T_{cl}) \quad (2.55)$$

where  $q_s(T_{cl})$  is the saturation mixing ratio at the cloud temperature  $T_{cl}$ . For convenience we define the quantity

$$h_1^* = c_p T_1 + gz_1 + Lq_s(T_1) \quad (2.56)$$

where  $T_1$  is the temperature of the air surrounding the clouds at level 1. Eliminating  $gz_1$  from Eqs. (2.55) and (2.56), the temperature difference between the clouds and the surrounding air at level 1 becomes

$$T_{cl} - T_1 = \frac{1}{1 + \gamma_1} \frac{h_c - h_1^*}{c_p} \quad (2.57)$$

where

$$\gamma_1 = \frac{L}{c_p} \left( \frac{\partial q_s}{\partial T} \right)_1 \approx \frac{L}{c_p} \frac{q_s(T_{cl}) - q_s(T_1)}{T_{cl} - T_1} \quad (2.58)$$

Thus it can be seen from Eq. (2.57) that when  $h_c > h_1^*$  the temperature in the clouds at level 1 is warmer than that in the surroundings, and any convection that has been initiated will tend to continue.

We now seek to determine the value of  $h_c$  in terms of the Mintz-Arakawa two-level model's parameters. To do this we assume that all the entrainment takes place at level 3, and thus the vertical mass flux ( $M$ ) through the cloud above level 3 becomes

$$M = M_b \eta \quad (2.59)$$

where  $M_b$  is the vertical mass flux through the bottom of the cloud and  $\eta$  is the entrainment factor. When there is entrainment,  $\eta > 1$ , and the static energy in the cloud is a mixture of the static energy entering the base of the cloud,  $h_b$ , and that of the surrounding air,  $h_3$ . Thus we have

$$h_c = h_3 + \frac{1}{\eta} (h_b - h_3) \quad (2.60)$$

What is assumed for the amount of entrainment will therefore determine the value of  $h_c$  in Eq. (2.57) and thus the existence of stability in the model.

In the following subsections, the value of  $\eta$  for each type of convection will be discussed and the stability criteria derived. The criteria will then be used to determine the temperature and moisture changes resulting from the convection.

a. Middle-Level Convection. In middle-level convection we assume that the entrainment at level 3 is much larger than the mass flux through the bottom of the cloud. Mathematically, it can be represented by setting  $\frac{1}{\eta} = 0$  while leaving  $\eta M_b$  finite. Thus from Eq. (2.60) we have  $h_c = h_3$ , and from Eq. (2.57) the condition for middle-level convection becomes  $h_3 > h_1^*$ . The parameters  $h_3$  and  $h_1^*$ , rewritten in terms of the potential temperatures and mixing ratios at levels 1 and 3, are

$$\frac{h_1^*}{c_p} = \theta_3 \left( \frac{p_s}{p_o} \right)^\kappa + (\theta_1 - \theta_3) \left( \frac{p_2}{p_o} \right)^\kappa + \frac{L}{c_p} q_s(T_1) \quad (2.61)$$

$$\frac{h_3}{c_p} = \theta_3 \left( \frac{p_s}{p_o} \right)^\kappa + \frac{L}{c_p} q_3 \quad (2.62)$$

where

$$\theta_3 \left( \frac{p_s}{p_o} \right)^{\kappa} \approx T_3 + \frac{g}{c_p} z_3 \quad (2.63)$$

and

$$(\theta_1 - \theta_3) \left( \frac{p_2}{p_o} \right)^{\kappa} = \left( T_1 + \frac{g}{c_p} z_1 \right) - \left( T_3 + \frac{g}{c_p} z_3 \right) \quad (2.64)$$

To determine the temperature change at levels 1 and 3 due to this convection, we introduce the concept of "dry" static energy, S, where

$$S \equiv c_p T + gz \quad (2.65)$$

Considering convection only, the continuity equation for S at level 1 is

$$\frac{\partial p S_1}{\partial t} = - \frac{\partial (\eta M_b S_1)}{\partial z} \quad (2.66)$$

which may be approximated by

$$\frac{\Delta p}{g} \frac{\partial S_1}{\partial t} = \eta M_b (S_{c1} - S_2) \quad (2.67)$$

Neglecting the time change of the geopotential and using Eq. (2.57) we may write Eq. (2.67) as

$$\frac{\partial T_1}{\partial t} = \frac{g}{c_p \Delta p} \eta M_b \left[ \frac{1}{1 + \gamma_1} (h_3 - h_1^*) + (S_1 - S_2) \right] \quad (2.68)$$

With similar approximations, the temperature change at level 3 is given by

$$\frac{\partial T_3}{\partial t} = \frac{g}{\Delta p} \frac{\eta M_b}{c_p} (S_2 - S_3) \quad (2.69)$$

Equations for the mixing ratios at levels 1 and 3 can be derived in a similar fashion. However, in the model all the moisture is assumed to be carried at level 3, and thus the change of  $q_3$  due to convection becomes

$$\begin{aligned} \frac{\partial q_3}{\partial t} &= \frac{g}{\Delta p} \eta M_b [q_s(T_{cl}) - q_3] \\ &= \frac{g}{\Delta p} \eta M_b [q_s(T_1) - q_3 + \frac{\gamma_1}{1 + \gamma_1} \frac{1}{L} (h_3 - h_1^*)] \end{aligned} \quad (2.70)$$

Here, Eq. (2.57) has been used to eliminate  $q_s(T_{cl})$ .

To eliminate the unknown mass flux in Eqs. (2.68) to (2.70), we relate  $\eta M_b$  to the relaxation time,  $\tau_r$ , of free cumulus convection. As a result of convection, the instability of the layer diminishes and  $h_3 \rightarrow h_1^*$ . The time rate of change of  $(h_3 - h_1^*)$  is given by

$$\begin{aligned} \frac{\partial}{\partial t} (h_3 - h_1^*) &= \frac{\partial}{\partial t} (S_3 - S_1) + L \frac{\partial q_3}{\partial t} - L \frac{\partial q_s(T_1)}{\partial T_1} \frac{\partial T_1}{\partial t} \\ &= - \frac{g}{\Delta p} \eta M_b \frac{2 + \gamma_1}{1 + \gamma_1} [(h_3 - h_1^*) + \frac{1}{2} (1 + \gamma_1) (S_1 - S_3)] \end{aligned} \quad (2.71)$$

If the instability diminishes exponentially with e-folding time  $\tau_r$ , then

$$\eta M_b = \frac{1}{\tau_r} \frac{\Delta p}{g} \frac{1 + \gamma_1}{2 + \gamma_1} \left[ \frac{h_3 - h_1^*}{h_3 - h_1^* + \frac{1}{2} (1 + \gamma_1) (S_1 - S_3)} \right] \quad (2.72)$$

When Eq. (2.72) is combined with (2.68) and (2.69), the change in temperature at levels 1 and 3 [over the time interval  $(5\Delta t)$  between heating calculations] due to the release of latent heat is given by

$$(\Delta T_1)_{CM} = \frac{h_3 - h_1^*}{c_p(2 + \gamma_1)} \frac{5\Delta t}{\tau_r} \quad (2.73)$$

$$(\Delta T_3)_{CM} = \frac{(\Delta T_1)_{CM} (1 + \gamma_1) LR/2}{(h_3 - h_1^*)/c_p + (1 + \gamma_1) LR/2} \quad (2.74)$$

where  $\gamma_1 = (L/c_p) 5418 \deg q_s (T_1) T_1^{-2}$  and  $LR = (\theta_1 - \theta_3)(p_2/p_0)^{\kappa}$  is a "nominal lapse rate." In this model, the relaxation time,  $\tau_r$ , is taken to be 1 hour. From Eqs. (2.70) and (2.73) the change in moisture at level 3 is given by

$$(\Delta q_3)_{CM} = \frac{c_p}{L} \left[ (\Delta T_1)_{CM} + (\Delta T_3)_{CM} \right] \quad (2.75)$$

As in Eq. (2.50), the precipitation rate due to middle-level convection is given by

$$P_{CM} = (\pi/2g\rho_w)(\Delta q_3)_{CM} \quad (2.76)$$

Type-1 clouds may be produced by this middle-level convection (see Subsection F.6), and the associated convective precipitation rate is illustrated in Map 13, Chapter IV.

b. Boundary-Layer Temperature and Moisture. If middle-level convection does not occur, either "penetrating convection" or "low-level convection" may. Since both of these convection types originate at the air/ground interface, it is convenient to discuss first the computation of the moisture,  $q_4$ , and air temperature,  $T_4$ , at the surface along with other air/ground interaction parameters. A thin

boundary layer is assumed at the air/ground interface, with the subscript "4" referring to values at the top of the boundary layer and the subscript "g" referring to values at the bottom of the layer, just above the ground or water surface.

We assume that the flux of static energy [see Eq. (2.54)] from the surface into the bottom of the boundary layer is equal to the flux out the top. We neglect horizontal convergence in this thin boundary layer and also assume negligible geopotential difference between its top and bottom. Thus the flux of static energy from the surface may be approximated by

$$\Gamma_h = \rho_4 C_D W (h_g - h_4) \quad (2.77)$$

where

$$W = |\vec{V}_g|^n + G \quad (2.78)$$

is a surface-wind parameter corrected for gustiness and  $C_D$  is the drag coefficient. Implied in Eq. (2.77) are the assumptions that the eddy-diffusion coefficient for the static energy can be approximated by that for momentum, and that a constant transfer coefficient may be used in the boundary layer. Equating (2.77) to the flux through the top of the boundary layer, we obtain

$$\rho_4 C_D W (h_g - h_4) = \rho_4 A_v \frac{h_4 - h_3}{z_3} \quad (2.79)$$

where  $A_v$  is the vertical eddy-diffusion coefficient. Solving Eq. (2.79) for  $h_4$  we obtain

$$h_4 = (EDR)h_3 + (1 - EDR)h_g \quad (2.80)$$

where  $h_3$  is given by Eq. (2.62),  $h_g$  is given by

$$\frac{h_g}{c_p} = T_g + \frac{L}{c_p} q_g \quad (2.81)$$

and

$$EDR = \frac{A_v/z_3}{A_v/z_3 + C_D W} \quad (2.82)$$

In the present version of the model it is assumed that  $A_v = 1 |\vec{V}_s|^{\pi} \text{ m}^2 \text{ sec}^{-1}$ , where the surface wind  $\vec{V}_s$  is in  $\text{m sec}^{-1}$ .

In order to obtain the surface moisture,  $q_4$ , and temperature,  $T_4$ , we now write the parameter  $h_4$  from Eq. (2.54) as

$$\frac{h_4}{c_p} = T_4 + \frac{L}{c_p} q_4 \quad (2.83)$$

By defining the values of  $q_g$  and  $q_4$ , one may solve Eqs. (2.80) and (2.83) for  $T_4$  in terms of the surface parameters  $T_g$  and  $GW$  and the static energy at level 3. In general the ground temperature,  $T_g$ , and the ground wetness,  $GW$  ( $0 \leq GW \leq 1$ ), are available from the previous time step, along with the level-3 temperature and moisture. From these data, the relative humidities at levels 3 and 4 may be determined from

$$RH_3 = \frac{q_3}{q_s(T_3)} \quad (2.84)$$

and

$$RH_4 = \frac{(2GW)(RH_3)}{GW + RH_3} \quad (2.85)$$



where  $RH_4$  is the harmonic mean of  $RH_3$ , the relative humidity at level 3, and the ground wetness, GW. The ground-level mixing ratio is assumed to be directly proportional to the ground wetness. Hence

$$q_g = GW q_s(T_g) \quad (2.86)$$

where  $q_s(T_g)$  is calculated from  $T_g$  in the usual fashion [see Eq. (2.40)],

$$q_s(T_g) = \frac{0.622 e_s(T_g)}{p_4 - e_s(T_g)} \quad (2.87)$$

and the ground-level saturation vapor pressure is given by

$$e_s(T_g) = \min[e_o \exp(A_e - B_e/T_g), p_4/16.62] \quad (2.88)$$

The mixing ratio at level 4 can now be obtained from Eq. (2.85) and an extrapolation of  $q_s(T_g)$  to level 4. Thus

$$\begin{aligned} q_4 &= RH_4 \left[ q_s(T_g) + \Delta z \frac{dq_s(T_g)}{dT} \frac{dT}{dz} \right] \\ &= RH_4 \left[ q_s(T_g) + \frac{c_p}{L} \gamma_g (T_4 - T_g) \right] \end{aligned} \quad (2.89)$$

where  $\gamma_g$  is evaluated from

$$\gamma_g = \frac{L}{c_p} \frac{dq_s(T_g)}{dT} = \frac{L}{c_p} 5418 \deg \frac{q_s(T_g)}{T_g^2} \quad (2.90)$$

Using Eqs. (2.83), (2.89), and (2.80), the temperature at level 4 becomes finally

$$T_4 = \begin{cases} \frac{\tilde{h}_4 - RH_4 \left[ \frac{L}{c_p} q_s(T_g) - \gamma_g T_g \right]}{1 + RH_4 \gamma_g}, & \text{if } T_4 \left( \frac{p_0}{p_4} \right)^\kappa \leq \theta_3 \\ \theta_3 \left( \frac{p_4}{p_0} \right)^\kappa, & \text{otherwise} \end{cases} \quad (2.91)$$

where  $\tilde{h}_4$  is the value of the static energy at level 4 as given by Eq. (2.80). The condition on  $T_4$  given by Eq. (2.91) is invoked to prevent a super-adiabatic lapse rate between levels 4 and 3. From the quantities  $T_4$  and  $q_4$  given by Eqs. (2.89) and (2.91) the convection parameter  $h_4$  defined by Eq. (2.83) may then be evaluated, although the quantities  $T_4$  and  $q_4$  will be *redefined* later if penetrating or low-level convection occurs [see Eqs. (2.96) and (2.97) below].

c. Penetrating and Low-Level Convection. In the model, both penetrating convection and low-level convection are mutually exclusive with middle-level convection. Thus, the first criterion to be met is that the layer between level 3 and level 1 be stable, i.e., that  $h_3 < h_1^*$ . A second criterion, similar to Eq. (2.57) for middle-level convection, is obtained from instability conditions for the layer between levels 4 and 3. Thus we first write

$$T_{c3} - T_3 = \frac{1}{1 + \gamma_3} \frac{h_c - h_3^*}{c_p} \quad (2.92)$$

where  $T_{c3}$  is the temperature of the rising air in the clouds at level 3,

$$\gamma_3 = \frac{L}{c_p} \frac{dq_s(T_3)}{dT} = \frac{L}{c_p} 5418 \deg \frac{q_s(T_3)}{T_3^2} \quad (2.93)$$

and

$$\frac{h_3^*}{c_p} = \theta_3 \left( \frac{p_s}{p_0} \right)^\kappa + \frac{L}{c_p} q_s(T_3) \quad (2.94)$$

For penetrating and low-level convection we assume that there is no entrainment at level 3 ( $\eta = 1$ ), and from Eq. (2.60) we then find  $h_c = h_b$ . Further, we take the static energy at the base of the cloud,  $h_b$ , to be equal to its value at the top of the boundary layer,  $h_4$ . Therefore the second criterion for penetrating and low-level convection becomes  $h_4 > h_3^*$ , along with the primary criterion  $h_3 < h_1^*$ . When these two conditions are met, we may then discriminate between penetrating and low-level convection. From Eq. (2.57) with  $h_c = h_4$  we see that if  $h_4 \geq h_1^*$ , convection can penetrate into the stable layer above level 3 and reach all the way to level 1. This is therefore the distinguishing condition for penetrating convection. If, on the other hand,  $h_4 < h_1^*$ , the convection stops at level 3. This is therefore the condition for low-level convection.

In the case of low-level convection, it is assumed that  $h_4$  is modified to  $h_3^*$ , because of the process of transporting static energy out of the boundary layer. This is equivalent to assuming that static energy in the cloud becomes  $h_3^*$ . Low-level convection may produce type-3 clouds (see Subsection F.6), and condensation and precipitation are not allowed to occur; all the moisture transported as clouds is assumed to evaporate again within the same layer with no release of latent heat. The effect of this type of convection is thus felt only in the vertical transport of sensible heat and in surface evaporation, where it alters the surface moisture and temperature.

Indicating by primes the values *prior* to modification by low-level convection, we may write

$$h_4 = h_4' - (h_4' - h_3^*) \quad (2.95)$$

Substituting the definitions of  $h_4$  and  $h_4'$  into Eq. (2.95) and using Eq. (2.89) for the old and new mixing ratios at level 4, the surface temperature and mixing ratios are given, after convection, as

$$T_4 = T_4' - \frac{(h_4' - h_3^*)/c_p}{1 + RH_4 \gamma_g} \quad (2.96)$$

$$q_4 = \frac{1}{L} \left( h'_4 - \frac{T_4}{c_p} \right) \quad (2.97)$$

The temperature and mixing-ratio adjustments at level 4 given by Eqs. (2.96) and (2.97) also occur in the case of penetrating convection. To find the change in the temperature and mixing ratios at levels 3 and 1 in this case we continue to assume modification of  $h_4$  to  $h_3^*$ , and follow the same procedure used in middle-level convection. Thus, as in Eqs. (2.68) and (2.69) and using  $h_3^*$  as the static energy in the cloud, we obtain

$$\frac{\partial T_1}{\partial t} = \frac{g}{c_p \Delta p} M_b \frac{1}{1 + \gamma_1} (h_3^* - h_1^*) + \frac{S_1 - S_2}{c_p} \quad (2.98)$$

and

$$\frac{\partial T_3}{\partial t} = \frac{g}{\Delta p} M_b \frac{S_2 - S_4}{c_p} \quad (2.99)$$

To determine the value of the mass flux,  $M_b$ , we assume, as in the case of middle-level convection, that the penetrating convection decays with a relaxation time  $\tau_r$ . Here  $M_b$  is determined by the time required to remove the instability in the layer from level 4 to level 3, i.e., the time required for  $h'_4$  to approach  $h_3^*$ . With this assumption, the mass flux becomes

$$M_b = \frac{1}{\tau_r} \frac{\Delta p}{g} \frac{h'_4 - h_3^*}{EDR \left( \frac{h_3^* - h_1^*}{1 + \gamma_1} + S_1 - S_2 \right) + (1 + \gamma_3)(S_2 - S_4)} \quad (2.100)$$

Using Eqs. (2.98), (2.99), and (2.100), the temperature changes at the levels 1 and 3 due to penetrating convection over the time interval  $5\Delta t$  are given by

$$(\Delta T_1)_{CP} = \frac{h_4 - h_3^*}{c_p \tau} \tau_1 \frac{5\Delta t}{\tau_r} \quad (2.101)$$

$$(\Delta T_3)_{CP} = \frac{h_4 - h_3^*}{c_p \tau} \tau_2 \frac{5\Delta t}{\tau_r} \quad (2.102)$$

where

$$\tau_1 = \frac{h_3^* - h_1^*}{(1 + \gamma_1)c_p} + \frac{LR}{2} \quad (2.103)$$

$$\tau_2 = \left(\frac{LR}{2}\right) + \theta_3 \left(\frac{p_4}{p_0}\right)^\kappa - T_4 \quad (2.104)$$

$$\tau = \begin{cases} \text{EDR } \tau_1 + (1 + \gamma_3)\tau_2, & \text{if } \tau \geq 0.001 \\ 0.001 & , \text{ otherwise} \end{cases} \quad (2.105)$$

and  $\tau_r$  is the convection relaxation time as before. As with the middle-level convection, all the moisture condensed (and hence precipitated) is assumed to originate in the lower layer, so that the level-3 moisture change due to penetrating convection is given by

$$(\Delta q_3)_{CP} = \frac{c_p}{L} \left[ (\Delta T_1)_{CP} + (\Delta T_3)_{CP} \right] \quad (2.106)$$

Type-1 clouds may be produced by this convection (see Subsection F.6), and the precipitation rate due to penetrating convection is given by

$$P_{CP} = (\pi/2g\phi w)(\Delta q_3)_{CP} \quad (2.107)$$

This contributes to the total convective precipitation rate illustrated in Map 13, Chapter IV.

#### 4. Evaporation

The evaporation rate per unit area from the surface is approximated by an equation similar to (2.77) for the flux of static energy from the surface. Thus

$$E = \rho_4 C_D W (q_g - q_4) \quad (2.108)$$

where  $\rho_4 = p_s (RT_4)^{-1}$  with  $R$  the gas constant,  $p_s$ , the surface (level-4) pressure, and  $T_4$  and  $q_4$  are given by Eqs. (2.96) and (2.97) if penetrating or low-level convection exists, and otherwise by Eqs. (2.91) and (2.89). The ground-level value of the mixing ratio is given by

$$q_g = GW q_{se}(T_{gr}) \quad (2.109)$$

where  $q_{se}(T_{gr})$  is the effective saturation mixing ratio at the bottom of the boundary layer after a correction to include the effects of the radiation balance at the surface on the ground-level temperature (see Subsection G.3). Thus

$$q_{se} = q_s(T_g) + \frac{dq_s(T_g)}{dT} (T_{gr} - T_g) \quad (2.110)$$

where  $T_{gr}$  is the new value of  $T_g$  calculated to include the radiation.

The evaporation thus calculated can be either positive or negative, and is available as a separate output from the program (see Map 14, Chapter IV). The moisture at level 3 will be changed in direct proportion to this evaporation. Thus, over the time interval  $5\Delta t$ , the contribution by evaporation to the total moisture balance at level 3 (see following subsection) is given by

$$(\Delta q_3)_E = \frac{2g}{\pi} \cdot E \cdot 5\Delta t \quad (2.111)$$

### 5. Moisture Balance and Ground Water

Moisture balance is maintained both in the form of moisture at level 3 and as the ground water on the land. The ocean, ice, and snow are considered both as infinite sources (for evaporation) and infinite sinks (for precipitation, negative evaporation, and runoff). Although the upper-level moisture is calculated as a function of lower-level moisture for radiation purposes, the total amount at the upper level is otherwise considered to be negligible, as is any transport between the upper and lower layers of the model.

The level-3 moisture balance is calculated from

$$(q_3)_{\text{new}} = (q_3)_{\text{old}} + (\Delta q_3)_{\text{TOTAL}} \quad (2.112)$$

where  $(\Delta q_3)_{\text{TOTAL}}$  is the sum of the level-3 moisture changes due to middle-level convection, CM, or penetrating convection, CP, large-scale condensation, LS, and evaporation, E. Thus the expression for the moisture-source term of Eq. (2.35) becomes

$$\begin{aligned} 2mng(E - C) &= \frac{\Pi}{5\Delta t} (\Delta q_3)_{\text{TOTAL}} \\ &= \frac{\Pi}{5\Delta t} \left[ (\Delta q_3)_E - (\Delta q_3)_{LS} - (\Delta q_3)_{CM} - (\Delta q_3)_{CP} \right] \end{aligned} \quad (2.113)$$

The ground water is carried as the variable GW, which varies between 0 for dry ground and 1 for saturated ground. For ocean, ice, or snow, GW is always considered to be 1. This quantity is used in the determination of ground temperature and evaporation, and is recalculated (for land) after the level-3 moisture balance has been determined. If  $(\Delta q_3)_{\text{TOTAL}}$  is negative (a decrease in level-3 moisture), enough precipitation occurs for runoff to be calculated. If the ground is not saturated (GW < 1) then the runoff is taken as 0.5 GW; if the ground is saturated, the runoff is taken as unity. The new ground wetness is then given by

$$(GW)_{new} = (GW)_{old} + (1 - \text{runoff})(\Delta q_3)_{TOTAL} \frac{1}{GWM} \frac{\pi}{2g} \quad (2.114)$$

where GWM is the maximum mass of water per unit area which the ground can absorb (here assumed to be  $30 \text{ g/cm}^2$ ), and the factor  $\pi/2g$  is the air mass in a vertical column of unit area in the lower model layer. If  $(\Delta q_3)_{TOTAL}$  is not negative, because evaporation is greater than precipitation, the runoff is zero and Eq. (2.114) represents the net decrease of moisture at the ground. If  $(GW)_{new} < 0$  then  $(GW)_{new}$  is set to zero, and if  $(GW)_{new} > 1$  it is set to 1.

## 6. Clouds

The type of clouds present in the model depends upon which condensation and/or convection processes have occurred. The amount of cloud cover depends upon the relative humidity at level 3,  $RH_3$ , for convective clouds, whereas a complete overcast is assumed for clouds caused by large-scale condensation. Figure 2.2 shows the assumed physical dimensions of the various cloud types. Although the clouds are only parameterized entities as far as the moisture is concerned, they must have physical dimensions for the radiation calculations. In the present version of the program, type-1 clouds cannot coexist with other types in any given grid cell; types 2 and 3 may coexist.

Type-1 clouds may be described as towering cumulus, having their bases at level 3 and their tops at level 1. They exist if either middle-level or penetrating convection occurs. The amount of cloud cover (given as the fraction of the sky covered with clouds) is defined by  $CL = -1.3 + 2.6 RH_3$ . If  $CL \leq 0$  the sky is defined to be clear. This convection therefore does not create clouds unless the relative humidity at level 3 is greater than 50 percent. If  $CL > 1$  it is reset to 1, implying a completely cloudy sky.

Type-2 clouds may be described as a heavy overcast with base at level 3 and top at level 2. They exist if large-scale condensation takes place (as described in Subsection F.2 above), and if type-1 clouds do not exist (since strong convection would destroy these clouds).



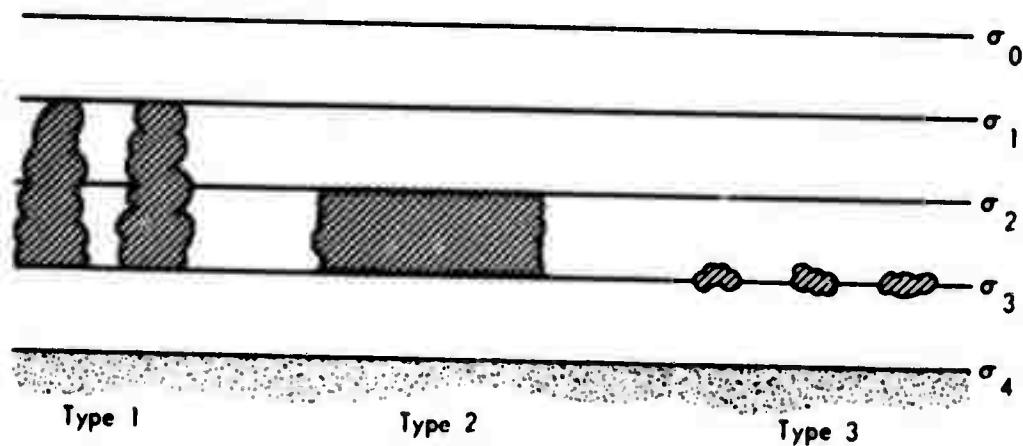


Fig. 2.2 -- Schematic representation of convective cloud types. Type-1 cloud represents either penetrating or middle-level convection and is assumed to extend from level  $\sigma_3$  to  $\sigma_1$ , type-2 cloud represents large-scale condensation and is assumed to extend from level  $\sigma_3$  to  $\sigma_2$ , and type-3 cloud represents low-level cumulus convection and is assumed to be confined to level  $\sigma_3$  itself.

When type-2 clouds are present they always form a completely overcast sky -- i.e.,  $CL = 1$  or  $0$ .

Type-3 clouds may be described as shallow cumulus with bases and tops both at level 3. They exist if there is low-level convection but no penetrating convection. The cloud amount is again defined as  $CL = -1.3 + 2.6 RH_3$ , with  $CL$  reset to 1 if  $CL > 1$  and with  $CL \leq 0$  meaning a clear sky. This cloud type could possibly coexist with type 2, but if so it would not affect the radiation, since cloud type 2 is a complete overcast in the same region.

### 7. Effective Water-Vapor Content

To determine the effect of the moisture on radiation we must estimate the entire vertical profile of  $q$  from the single value  $q_3$ . The  $q_3$  value used here is a revised one, including the effects of large-scale condensation, but not including changes due to convective condensation or evaporation. If  $q_3 < 10^{-5}$  it is set equal to  $10^{-5}$ . Above 120 mb the vapor pressure is assumed to be constant with height, with the value  $0.3316 \text{ dynes/cm}^2$  corresponding to the frost-point temperature 190 deg K, as suggested by Murgatroyd (1960). Thus

$$q \approx 0.622 \left( \frac{0.3316}{p_{\text{cgs}}} \right) = \frac{.206255}{p_{\text{cgs}}}, \quad p < 120 \text{ mb} \quad (2.115)$$

where  $p_{\text{cgs}}$  is pressure in cgs units ( $\text{dynes/cm}^2$ ). Below 120 mb it is assumed that

$$\frac{q}{q_3} = \left( \frac{p}{p_3} \right)^{K(p_3, q_3)}, \quad p \geq 120 \text{ mb} \quad (2.116)$$

where  $K$  is evaluated by matching  $q$  from Eqs. (2.115) and (2.116) at the 120-mb level

$$K(p_3, q_3) = \frac{\ln(q_3 / 1.7188 \times 10^{-6})}{\ln(p_3 / 120 \text{ mb})} \quad (2.117)$$

The effective water-vapor amount per unit area in a vertical column below a given level,  $n$ , with a pressure-broadening correction term included, is defined to be

$$u_n^* \equiv \int_{z_4}^{z_n} \rho \left( \frac{p}{p_0} \right) q \, dz = \frac{1}{g} \int_{p_n}^{p_4} \left( \frac{p}{p_0} \right) q \, dp \quad (2.118)$$

Combined with the values of  $q$  defined above, this becomes, for level  $n$ ,

$$u_n^* = \frac{q_3 (p_3)^2}{g p_0 (2 + K)} \left[ \left( \frac{p_4}{p_3} \right)^{2+K} - \left( \frac{p_n}{p_3} \right)^{2+K} \right] \quad (2.119)$$

and for the entire atmospheric column, including the stratosphere, the effective water-vapor content becomes

$$u_\infty^* = \frac{q_3 (p_3)^2}{g p_0 (2 + K)} \left[ \left( \frac{p_4}{p_3} \right)^{2+K} - \left( \frac{p(120 \text{ mb})}{p_3} \right)^{2+K} \right] + 2.526 \times 10^{-5} \quad (2.120)$$

where the additive term is the effective vapor amount above 120 mb, and where  $q_3$  is set equal to  $10^{-5}$  if it is  $< 10^{-5}$ . The effective vapor content of clouds is described in the following section.

#### G. RADIATION AND HEAT BALANCE

In this section the heat budget of the earth/atmosphere system is discussed and the expressions which are used to evaluate the diabatic-heating terms in the thermodynamic equations, (2.31) and (2.32), are developed, together with those expressions used to determine the surface temperature over land and over ice-covered oceans.

In addition to being partly determined by the release of latent heat during convection (see Subsection F.3), the net heating rate at level 1 ( $\sigma = 1/4$ ) is also determined by the amount of solar radiation absorbed by, and the long-wave radiation emitted from, the layer  $\sigma = 0$

to  $\sigma = 1/2$ . The heating rate at level 3 ( $\sigma = 3/4$ ) is determined by the flux of sensible heat from the surface and the release of latent heat in large-scale condensation (Subsection F.2), in addition to the absorbed and emitted radiation and the convective latent heating in the layer  $\sigma = 1/2$  to  $\sigma = 1$ . The treatment of the short-wave (solar) radiation and the long-wave (terrestrial) radiation used in the model follows the discussion of Arakawa, Katayama, and Mintz (1969). The so-called short-wave radiation includes all the solar radiation, regardless of wavelength, and the parameterization for the attenuation of this radiation by Rayleigh scattering, for its reflection from the earth's surface and from clouds, and for its absorption in the atmosphere and in clouds is given in Subsection G.1. The treatment of the flux of long-wave radiation, which includes all that which is emitted by the atmosphere, clouds, and the earth's surface, is given in Subsection G.2.

The ground temperature,  $T_{gr}$ , needed to evaluate the evaporation, the sensible heat flux from the surface, and the net long-wave surface radiation is determined from the heat balance at the earth's surface in Subsection G.3, and in Subsection G.4 a discussion of the heat balance in the atmosphere and the expressions for the temperature change due to diabatic heating are given.

### 1. Short-Wave Radiation

The incoming solar radiation is immediately divided into two parts, that of wavelength  $\lambda < 0.9\mu$ , which is assumed to be subject to Rayleigh scattering only, and that of wavelength  $\lambda \geq 0.9\mu$ , which, in a clear atmosphere, is assumed to be subject to absorption only. The actual wavelength does not again enter into the model's treatment of radiation. The two parts of the radiation are designated  $S_O^S$  (part subject to scattering) and  $S_O^A$  (part subject to atmospheric absorption), and are approximated as

$$S_O^S = 0.651 S_O \cos \tau \quad (2.121)$$

$$S_O^A = 0.349 S_O \cos \tau \quad (2.122)$$

where  $S_0$  is the solar constant (adjusted for the earth/sun distance), and  $\zeta$  is the zenith angle of the sun. The rationale for this partitioning is described by Joseph (1966). A summary of the disposition of these components of the short-wave radiation for both clear and cloudy skies is given in Figs. 2.3 and 2.4, and is described in detail in the following paragraphs.

a. Albedo. The albedo of the clear atmosphere for the portion of the radiation assumed subject to (Rayleigh) scattering is given by

$$\alpha_0 = \min \{1, 0.085 - 0.247 \log_{10}[(p_s/p_0) \cos \zeta]\} \quad (2.123)$$

as deduced by Katayama using the estimate of Joseph (1966).<sup>+</sup> For an overcast atmosphere, the albedo for the scattered part of the radiation is composed of the contributions of Rayleigh scattering (by atmospheric molecules) and of Mie scattering (by cloud drops). The simplest useful formulation adopted by Katayama is

$$\alpha_{ac} = 1 - (1 - \alpha_0)(1 - \alpha_{c_1}) \quad (2.124)$$

where  $\alpha_{c_1}$  is the cloud albedo (for both  $S_0^A$  and  $S_0^S$ ), which is assumed to be given by

$$\begin{aligned} \alpha_{c_1} &= 0.7 && \text{for cloud type 1} \\ \alpha_{c_2} &= 0.6 && \text{for cloud type 2} \\ \alpha_{c_3} &= 0.6 && \text{for cloud type 3} \end{aligned} \quad (2.125)$$

The various cloud types are discussed in Subsection F.6 below.

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<sup>+</sup>In the program, the expression  $p_s/p_0$  in Eq. (2.128) was inadvertently coded as  $(p_s - p_T)(p_0 - p_T)^{-1}$ ; see instruction 10450 in COMP 3 in the listing of Chapter VII. This error, which is not thought to be serious, was brought to our attention by A. Katayama.

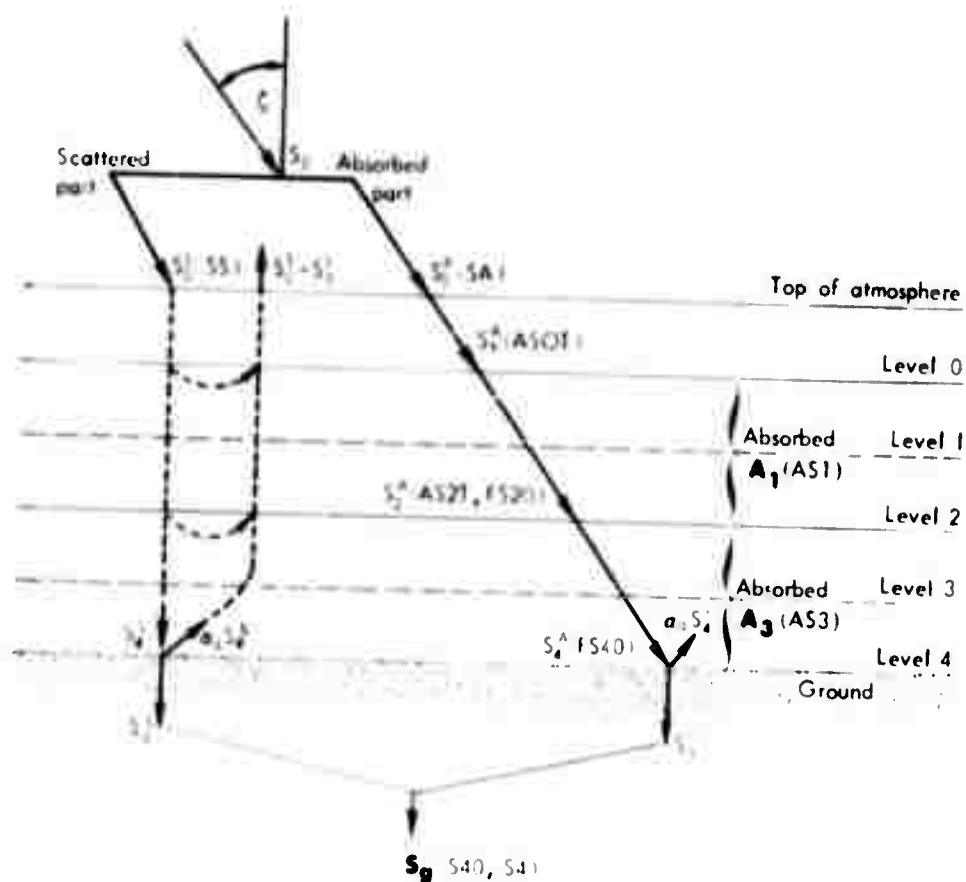


Fig. 2.3 -- Short-wave radiation in a clear atmosphere. The solid arrows indicate the path of radiative flux, while the dashed lines indicate a region of the atmosphere in which interaction occurs or in which a diffuse path is followed. The absorbed radiation  $A_1 = S_T^A - S_2^A$  and  $A_3 = S_2^A - S_4^A$ , according to (2.136). The program (FORTRAN) symbols are given in parentheses following certain of the physical symbols.

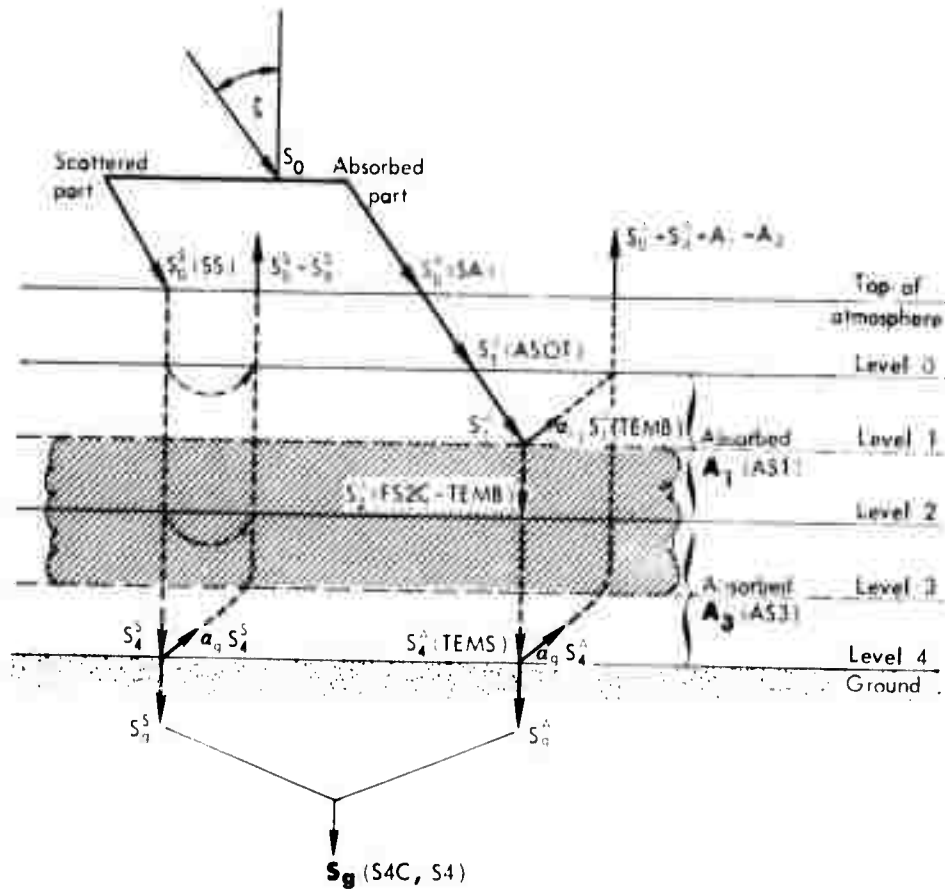


Fig. 2.4 -- Short-wave radiation in an overcast atmosphere, illustrated for cloud type 1. The absorbed radiation  $A_1 = S_T^A - S_2^A - S_1^A \alpha_{c1}$  according to (2.141), and  $A_3 = S_2^A - S_4^A$  according to (2.136). See also Fig. 2.3.

The ground albedo  $\alpha_g$  (again for both  $S_o^A$  and  $S_o^S$ ) is taken as

$$\begin{aligned}\alpha_g &= 0.07 && \text{for ocean} \\ &= 0.14 && \text{for land} \\ &= 0.45 \{1 + (\text{CLAT} - 10)^2 / [(\text{CLAT} - 30)^2 + (\text{CLAT} - 10)^2]\} && (2.126)^* \\ &&& \text{for south-polar ice and snow} \\ &= 0.40 \{1 + (\text{CLAT} - 5)^2 / [(\text{CLAT} - 45)^2 + (\text{CLAT} - 5)^2]\} \\ &&& \text{for north-polar ice and snow}\end{aligned}$$

These values for land, ice, and snow were developed by Katayama (1969) as approximations to the data of Posey and Clapp (1964). In the expressions for polar ice and snow, CLAT is the number of degrees poleward from the assumed northern or southern snowline (as appropriate) given by the functions SNØWN and SNØWS. The expression for north-polar ice and snow applies also for ice at latitudes between the two snow lines, with CLAT = 0.

b. The Radiation Subject to Scattering ( $S_o^S$ ). The part of the solar radiation which is assumed to be scattered does not interact with the atmosphere, except to be partly scattered back to space. Thus the only part with which we are concerned is that amount which reaches, and is absorbed by, the earth's surface. This is given by the expressions

$$\begin{aligned}S_g^{S'} &= S_o^S (1 - \alpha_g)(1 - \alpha_o) / (1 - \alpha_o \alpha_g) \\ &&& \text{for clear sky} \\ S_g^{S''} &= S_o^S (1 - \alpha_g)(1 - \alpha_{ac}) / (1 - \alpha_{ac} \alpha_g) && (2.127) \\ &&& \text{for overcast sky}\end{aligned}$$

Multiple reflections between sky and ground or between cloud base and

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\* These expressions are coded incorrectly in the program; see instructions 23720 and 23760, Chapter VII.



ground are accounted for by the terms in the denominators (see Joseph, 1966). For partly cloudy conditions (neither clear nor overcast) the scattered radiation absorbed at the earth's surface is

$$S_g^s = CL S_g^{s''} + (1 - CL) S_g^{s'} \quad (2.128)$$

where CL is the fractional cloudiness of the sky (see Subsection F.6). The absorption of this radiation by the ground affects the ground temperature, and subsequently affects the long-wave emission from the ground and the ground-level heat balance (see Figs. 2.3 and 2.4).

c. The Radiation Subject to Absorption ( $S_o^A$ ). The solar radiation subject to absorption is distributed as heat to the various layers in the atmosphere and to the earth's surface. The absorption is assumed to depend only upon the effective water-vapor content ( $u^*$ ) in a layer -- a quantity calculated from the model as previously outlined (see Subsection F.7). The absorptivity of a layer is given by the empirical formula

$$A(u^*, \zeta) = 0.271(u^* \sec \zeta)^{0.303} \quad (2.129)$$

Here the (dimensionless) coefficient 0.271 has been found by increasing the (dimensional) coefficient  $0.172 \text{ ly min}^{-1}$  of the MÜgge-MÖller absorption formula by 10 percent, as suggested by Manabe and Möller (1961), and then dividing by the total radiative flux subject to absorption, which is given by  $0.349 S_o = 0.698 \text{ ly min}^{-1}$  according to Eq. (2.122).

For clear sky the flux of  $S_o^A$  transmitted to a level  $n$  is given by

$$S_n^{A'} = S_o^A [1 - A(u_\infty^* - u_n^*, \zeta)] \quad (2.130)$$

and the flux absorbed in a layer between an upper level,  $i$ , and a lower level,  $j$ , is given by

$$\frac{A_{i+j}}{2} = S_i^{A'} - S_j^{A'} \quad (2.131)$$

For a cloudy sky the absorption in a cloud is calculated by assuming an equivalent water-vapor content which will absorb the same amount of radiation as would the cloud itself. These amounts are assumed in the present version of the model to be

$$\begin{aligned} u_{c1}^* &= 65.3 \text{ g/cm}^2 && \text{for cloud type 1} \\ u_{c2}^* &= 65.3 \text{ g/cm}^2 && \text{for cloud type 2} \\ u_{c3}^* &= 7.6 \text{ g/cm}^2 && \text{for cloud type 3} \end{aligned} \quad (2.132)$$

The incoming beam becomes diffuse in the cloud, and its path is assumed to be 1.66 times the vertical thickness of the cloud. Below the cloud the beam is still diffuse, and the factor 1.66 for path length is retained. Therefore we have the following expressions for the downward flux at various levels

$$S_1^{A''} = S_0^A \left[ 1 - A(u_\infty^* - u_1^*, \zeta) \right] \quad (2.133)$$

above the cloud at level 1

$$S_m^{A''} = S_0^A (1 - \alpha_c) \left\{ 1 - A \left[ (u_\infty^* - u_{CT}^*) \sec \zeta + 1.66 \frac{\Delta p_m}{\Delta p_c} u_c^* \right] \right\}^\dagger \quad (2.134)$$

inside a cloud at level m

$$S_j^{A''} = S_0^A (1 - \alpha_c) \left\{ 1 - A \left[ (u_\infty^* - u_{CT}^*) \sec \zeta + 1.66(u_c^* + u_{CB}^* - u_j^*) \right] \right\} \quad (2.135)$$

below a cloud at level j

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<sup>†</sup>The fraction  $\Delta p_m / \Delta p_c$ , which is equal to 1/2 when  $m = 2$  and type-1 clouds are present, has been inadvertently omitted from the model's present FORTRAN program.

where subscripts CT and CB refer to the cloud top and cloud bottom, respectively,  $\Delta p_c$  is total pressure thickness of the cloud, and  $\Delta p_m$  is the pressure thickness of the cloud above level m. The factor  $(1 - \alpha_c)$  accounts for reflection from the cloud top.

The flux absorbed in a layer in a cloudy sky will, in general, be  $\frac{A_{i+1}}{2} = S_1^{A''} - S_j^{A''}$ , in a fashion similar to Eq. (2.131) for clear sky.

If there is a cloud top anywhere within a layer, however, the flux absorbed by that layer will not be just the flux difference at the levels above and below the layer, since there will be a flux reflected from the cloud top and therefore lost. Thus, for the layer between levels i and j, the absorbed radiation is given by

$$\frac{A_{i+1}}{2} = S_1^{A''} - S_j^{A''} - S_{CT}^{A''} \alpha_c \quad (2.136)$$

where the last term is the flux reflected from the cloud top. When the sky is partly cloudy, the total flux at level i is given by a weighted average of the clear and overcast fluxes:

$$S_i^A = CL S_i^{A''} + (1 - CL) S_i^{A'} \quad (2.137)$$

That part of the flux subject to absorption which is actually absorbed by the ground is given by

$$(1 - \alpha_g) S_4^{A'} = S_g^{A'} \quad (2.138)$$

for clear sky, and by

$$\frac{(1 - \alpha_g) S_4^{A''}}{1 - \alpha_c \alpha_g} = S_g^{A''} \quad (2.139)$$

for completely cloudy (overcast) sky, where the factor  $1/(1 - \alpha_c \alpha_g)$  again accounts for multiple reflections between the ground and cloud base. For partly cloudy skies, the radiation absorbed by the ground is the sum

$$S_g^A = CL S_g^{A''} + (1 - CL) S_g^{A'} \quad (2.140)$$

The total solar radiation absorbed by the ground will be the sum of that part of the solar radiation subject to (atmospheric) absorption that is absorbed instead by the ground and that part subject to scattering (atmospheric) that is absorbed by the ground. Thus, from Eqs. (2.128) and (2.140), we have

$$S_g = S_g^A + S_g^s \quad (2.141)$$

## 2. Long-Wave Radiation

The calculation of the long-wave radiation, like that of the short-wave radiation, is based on an empirical transmission function depending primarily upon the amount of water vapor. The net upward long-wave radiation at a level  $i$  can be expressed as the sum of three terms

$$R_i = R_A + R_B + C_i \quad (2.142)$$

where  $R_A$  is the radiative flux downward from the atmosphere above the level  $i$ , and  $R_B$  is the flux from below. The term  $C_i$  was intended to be a correction term accounting for a possible large temperature difference between the level-4 air temperature,  $T_4$ , and the ground surface temperature,  $T_g$ . However, in the early stages of evolution of the Mintz-Arakawa program the two temperatures were assumed to be equal, and both were designated in the program with the same symbol. At the time the program was modified to calculate the two separately, a programming error was made whereby the terms were not changed consistently. In several statements the ground temperature,  $T_g$ , is used

in place of the air temperature  $T_4$ , and in the ground temperature correction term,  $C_1$ , the values of ground temperatures before and after the heating cycle ( $T_g$ ,  $T_{gr}$ ) are used in place of  $T_4$  and  $T_{gr}$ .

In this Report we have described what the program actually does, rather than what was intended. Those equations in which  $T_g$  was used in place of  $T_4$  are indicated throughout Subsections G.2 and G.3 by the symbol  $\sim$ . In future work, the program will be corrected and the effects of this error will be investigated.

The term  $C_1$  in Eq. (2.142) is thus now apparently a "correction" involving the change in the ground temperature during the heating time interval. This term depends upon all the various heat-exchange mechanisms in the program, including the other terms involving long-wave radiation. Therefore  $R_A + R_B$  is calculated first and the  $C_1$  term is left until later (see Subsection G.3). A schematic overview of the long-wave radiation balance is given in Fig. 2.5.

The fluxes at level 1 are given by the expressions

$$R_A = \sigma T_1^4 \bar{\tau}_A \quad (2.143)$$

$$R_B = (\sigma T_g^4 - \sigma T_1^4) \bar{\tau}_B \quad (2.144)$$

where  $\sigma$  is here the Stefan-Boltzman constant, and the empirical transmission functions are given by

$$\bar{\tau}_A = \tau(u_\infty^* - u_1^*) \quad (2.145)$$

$$\bar{\tau}_B = \frac{1 + \tau(u_1^*)}{2} \quad (2.146)$$

with

$$\tau(u^*) = 1 / (1 + 1.75 u^{*0.416}) \quad (2.147)$$

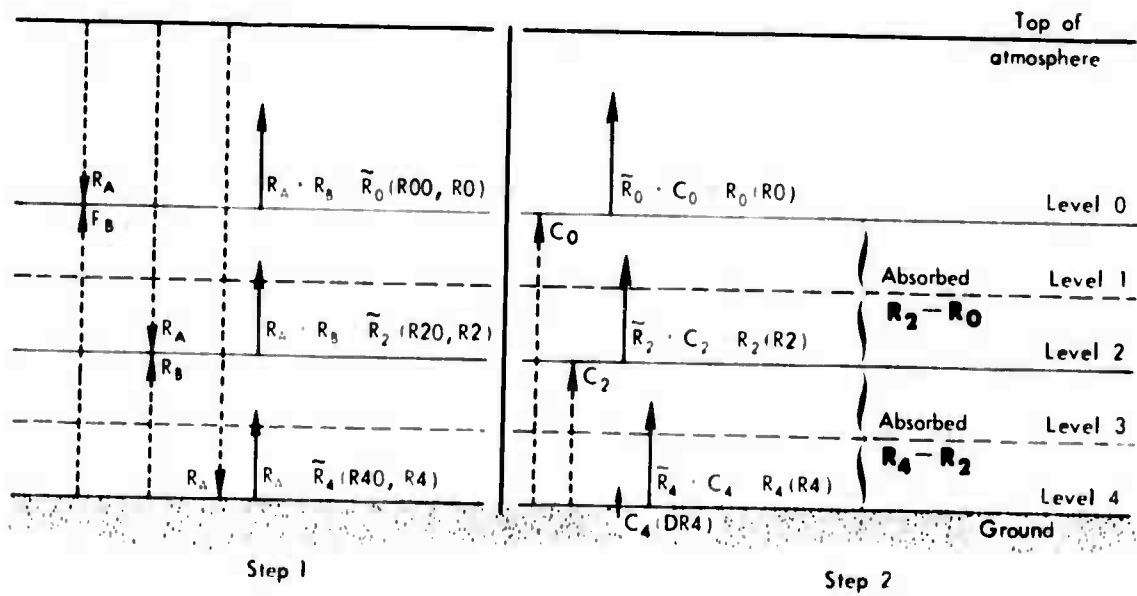


Fig. 2.5 -- Long-wave radiation in a clear atmosphere. See also Fig. 2.3.

as found by Katayama for the Callendar water-vapor transmission function. Here  $u^*$  is the effective vapor content defined in Subsection F.7. For a clear sky, if we define  $R'_1 \equiv R_A + R_B$ , we have at the three levels  $\sigma = 0$  ( $i = 0$ ),  $\sigma = 1/2$  ( $i = 2$ ), and  $\sigma = 1$  ( $i = 4$ ), where radiation is determined by:

$$R'_0 = \sigma T_0^4 \tau(u_\infty^* - u_0^*) + (\sigma T_g^4 - \sigma T_0^4) \frac{1 + \tau(u_0^*)}{2} \quad (2.148)+$$

$$R'_2 = \sigma T_2^4 \tau(u_\infty^* - u_2^*) + (\sigma T_g^4 - \sigma T_2^4) \frac{1 + \tau(u_2^*)}{2} \quad (2.149)+$$

$$R'_4 = \sigma T_g^4 \tau(u_\infty^*) \quad (2.150)+$$

Here the primes indicate a clear sky. To account for the absorption by  $CO_2$ , which is not included in the above expressions, the model incorporates a number of empirical modifications [due to Katayama (1969)] of the long-wave fluxes. We thus redefine the clear-sky fluxes given above as

$$R'_0 = 0.820 R'_0 \quad (2.151)$$

$$R'_2 = 0.736 R'_2 \quad (2.152)$$

$$R'_4 = \sigma T_g^4 \left[ 0.6 \sqrt{\tau(u_\infty^*)} - 0.1 \right] \quad (2.153)+$$

which are the clear-sky expressions used in the program. The expression for  $R'_4$  is similar to Brunt's formula.

Clouds are treated as opaque black bodies, and the cloud cover may consist of any of the model's three cloud types. Including empirical corrections, one uses the following expressions for the radiation in

completely overcast skies. For cloud type 1 (top at level 1, bottom at level 3)

$$R''_0 = 0.820 \left[ \sigma T_0^4 \tau(u_\infty^* - u_0^*) + (\sigma T_1^4 - \sigma T_0^4) \frac{1 + \tau(u_0^* - u_1^*)}{2} \right] \quad (2.154)$$

$$R''_2 = 0 \quad (2.155)$$

$$R''_4 = 0.85(\sigma T_g^4 - \sigma T_3^4) [1 + 3\tau(u_3^*)] / 4 \quad (2.156)^+$$

where the double primes indicate an overcast sky and  $R''_1 \equiv R_A + R_B$ . For cloud type 2 (top of cloud at level 2, bottom at level 3),

$$R''_0 = 0.820 \left[ \sigma T_0^4 \tau(u_\infty^* - u_0^*) + (\sigma T_2^4 - \sigma T_0^4) \frac{1 + \tau(u_0^* - u_2^*)}{2} \right] \quad (2.157)$$

$$R''_2 = [0.736\sigma T_2^4 \tau(u_\infty^* - u_2^*)] / 2^\dagger \quad (2.158)$$

$$R''_4 = \text{same as for cloud 1 [Eq. (2.156)]}$$

For cloud type 3 (top and bottom at level 3):

$$R''_0 = 0.820 \left[ \sigma T_0^4 \tau(u_\infty^* - u_0^*) + (\sigma T_3^4 - \sigma T_0^4) \frac{1 + \tau(u_0^* - u_3^*)}{2} \right] \quad (2.159)$$

$$R''_2 = 0.736 \left[ \sigma T_2^4 \tau(u_\infty^* - u_2^*) + (\sigma T_3^4 - \sigma T_2^4) \frac{1 + \tau(u_0^* - u_3^*)}{2} \right] \quad (2.160)$$

$$R''_4 = \text{same as for cloud type 1 [Eq. (2.156)]}$$

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<sup>†</sup> This  $R''_2$  is divided by 2 because the cloud top is assumed to be an irregular surface lying half-above, half-below level 2.



If we now define  $\tilde{R}_1$  as the net upward long-wave radiation for partly cloudy skies prior to the ground-temperature correction,  $R'_1$  and  $R''_1$  combine to give

$$\tilde{R}_1 = (1 - CL)R'_1 + (CL)R''_1 \quad (2.161)$$

where CL is the fractional cloudiness (see Subsection F.6).

Finally, after the ground temperature has been determined using  $\tilde{R}_1$  and the calculated short-wave radiation (among other quantities, as described in Subsection G.3 below), the long-wave radiation is calculated in its complete form  $R_1$  by applying the correction (C) given at level 4 by

$$C_4 = 4\sigma T_g^3(T_{gr} - T_g) \quad (2.162)+$$

where  $4\sigma T_g^3(T_{gr} - T_g)$  is an approximation to  $\sigma(T_{gr}^4 - T_g^4)$ . The complete long-wave flux at level 4 is thus given, according to Eq. (2.96), by

$$R_4 = \tilde{R}_4 + C_4 = (1 - CL)R'_4 + (CL)R''_4 + 4\sigma T_g^3(T_{gr} - T_g) \quad (2.163)+$$

At levels 2 and 0 the complete long-wave flux is similarly given by

$$R_2 = \tilde{R}_2 + C_2 = \tilde{R}_2 + 0.8(1 - CL)C_4\tau(u_2^*) \quad (2.164)$$

$$R_0 = \tilde{R}_0 + C_0 = \tilde{R}_0 + 0.8(1 - CL)C_4\tau(u_0^*) \quad (2.165)$$

where  $\tilde{R}$  is given by Eq. (2.161) and  $C_4$  by (2.162), and where the coefficient 0.8 is the correction factor for  $CO_2$  absorption. These are the long-wave radiation fluxes calculated in the program as the net transfers at the levels 4, 2, and 0, and are used in the preparation of the

long-wave radiative budgets for the layers 0 to 2 and 2 to 4 as well as for the surface (level-4) radiation budget in the output programs (see Chapter IV). The various components of these long-wave fluxes are summarized in Fig. 2.6.

### 3. Heat Balance at the Ground

The ground temperature,  $T_{gr}$ , as corrected for surface radiation and as used to find the evaporation, is itself obtained from the heat balance at the ground. The treatment of the heating of the ground depends first of all upon the character of the ground or underlying surface.

If the surface is ice-free ocean, it is considered to be an infinite heat reservoir whose surface temperature,  $T_g$ , is a specified function of position and does not change during the heating time interval ( $5\Delta t$ ). The new ground temperature,  $T_{gr}$ , is set equal to the old  $T_g$ .

Where the surface is bare land, snow-covered land, or ice-covered land, the ground is considered to be a perfect insulator with zero heat capacity. For these types of ground, the total flux of heat across the air/ground interface must be zero, according to

$$R_4 + \Gamma + H_E - S_g = 0 \quad (2.166)$$

where  $R_4$  is the long-wave radiation emitted from the surface,  $\Gamma$  is the sensible heat flux from the surface,  $H_E$  is the flux of latent heat due to evaporation from the surface, and  $S_g$  is the solar radiation absorbed by the ground.

For ice-covered ocean, the surface heat balance is modified to include conduction of heat through the ice,  $\tilde{B}$ , in which case Eq. (2.166) is changed to read

$$R_4 + \Gamma + H_E - S_g = \tilde{B} = B(T_o - T_{gr}) \quad (2.167)$$

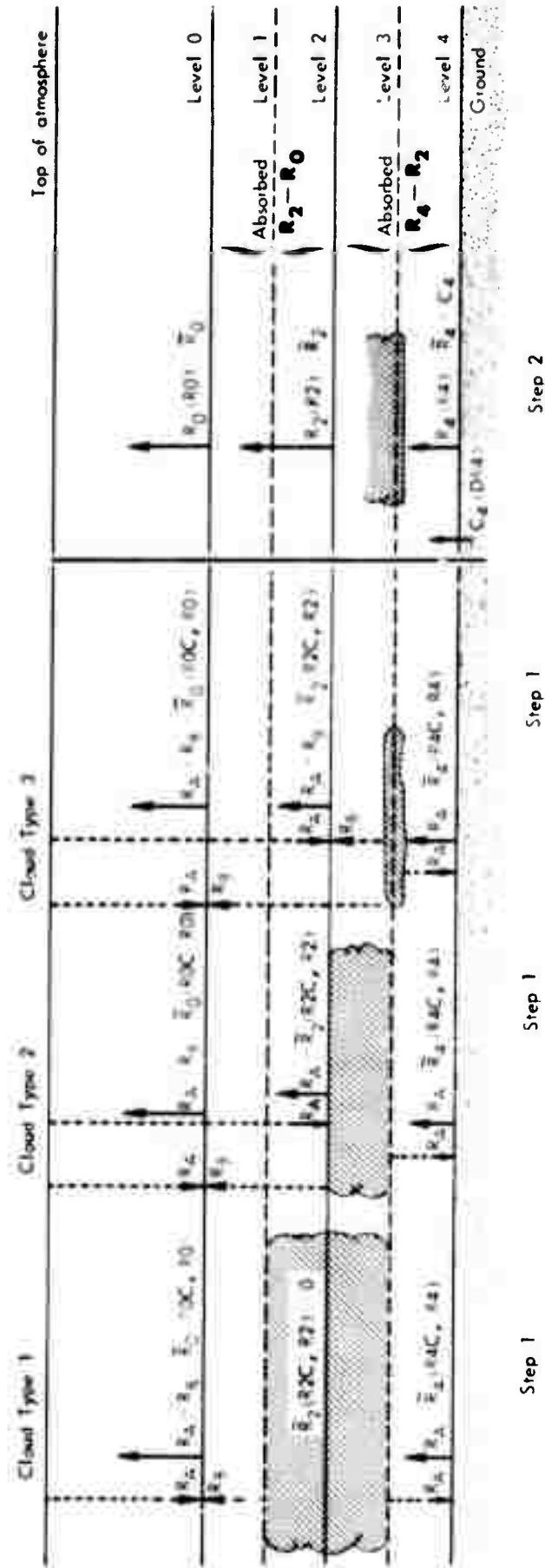


Fig. 2.6 -- Long-wave radiation in an overcast atmosphere (cloud types 1, 2, or 3). See also Fig. 2.3.

where  $T_o$  equals the freezing point of seawater (273.1 deg K). Equation (2.167) is applicable to the land, snow- and ice-covered land surfaces too, if we define  $B = 0$  for these locations; for sea ice the conduction coefficient  $B$  is equal to  $1.44 \text{ ly day}^{-1} \text{ deg}^{-1}$ , found from an assumed thermal conductivity of  $0.005 \text{ ly cm sec}^{-1} \text{ deg}^{-1}$  and an ice thickness of 300 cm. Note that, except for the solar radiation, these heating terms depend upon the as-yet-undetermined new value of the ground temperature,  $T_{gr}$ , as well as upon the old value,  $T_g$ , upon the temperature of the air,  $T_4$ , or upon the freezing point of sea water,  $T_o$ .

The heating terms are given by

$$R_4 = \tilde{R}_4 + \sigma(T_{gr}^4 - T_g^4) \quad (2.168)$$

where  $\tilde{R}$  is the long-wave radiation without the ground-temperature correction as given by Eq. (2.161) and  $\sigma(T_{gr}^4 - T_g^4)$  is the "correction" term. (See, however, Subsection G.2.) The sensible (turbulent) heat flux,  $\Gamma$ , is given by

$$\Gamma = C_\Gamma (T_{gr} - T_4) \quad (2.169)$$

where

$$C_\Gamma = \rho_4 c_p C_D W \quad (2.170)$$

where  $W$  is the surface wind speed, as corrected for gustiness in Eq. (2.78). The latent heat flux is given by

$$H_E = LE = C_\Gamma \frac{L}{c_p} \left\{ GW \left[ q_s(T_g) + \frac{dq_s(T_g)}{dT} (T_{gr} - T_g) \right] - q_4 \right\} \quad (2.171)$$

where Eqs. (2.108) and (2.109) have been used to evaluate the evaporation.

Substituting Eqs. (2.168), (2.169), and (2.171) for  $R_4$ ,  $\Gamma$ , and  $H_E$  into the heat-balance equation, (2.167), and approximating  $\sigma(T_{gr}^4 - T_g^4)$  by  $4\sigma T_g^3(T_{gr} - T_g)$ , we can solve for the unknown ground temperature  $T_{gr}$ . Thus, we have

$$T_{gr} = \frac{C_\Gamma \left( T_4 + \frac{L}{c_p} \left\{ q_4 + GW \left[ \frac{dq_s(T_g)}{dT} T_g - q_s(T_g) \right] \right\} \right) + S_g - \tilde{R}_4 + 4\sigma T_g^4 + BT_o}{C_\Gamma \left[ 1 + \frac{L}{c_p} \frac{dq_s(T_g)}{dT} GW \right] + 4\sigma T_g^3 + B} \quad (2.172)$$

Having found  $T_{gr}$ , we can complete the calculation of the individual radiation and heating terms  $R_4$  (and  $R_2$ ,  $R_0$  as in Subsection G.2),  $\Gamma$  and  $H_E$  from Eqs. (2.167) to (2.171), and the surface evaporation,  $E$ , from Eq. (2.108). The equations are applicable to an ocean surface as well as to land, ice, and snow: for oceans,  $T_{gr} = T_g$ , some of the terms will be zero, and there will be no correction terms for the long-wave radiation; for ice and snow, if the calculated value of  $T_{gr}$  is greater than  $T_o$  ( $= 273.1$  deg K) it is set equal to  $T_o$ .

#### 4. Heat Budget of the Atmosphere

The heat balance is maintained at the ground through the calculated ground temperature (see previous section), and at the levels 3 and 1 by means of the diabatic heating terms on the right-hand sides of Eqs. (2.31) and (2.32). After the temperature changes due to convective adjustment (see Subsection F.1), no further change is made until the end of all the radiation- and moisture-balance calculations. Then the change in temperature over the interval  $5\Delta t$  at levels 3 and 1 is given by

$$H_3 = 5\Delta t \dot{H}_3 \\ = (A_3 + R_4 - R_2 + \Gamma)(2g/\pi c_p)5\Delta t + (\Delta T_3)_{CM} + (\Delta T_3)_{CP} + (\Delta T_3)_{LS} \quad (2.173)$$

$$H_1 = 5\Delta t \dot{H}_1$$

$$= (A_1 + R_2 - R_0)(2g/\pi c_p)5\Delta t + (\Delta T_1)_{CM} + (\Delta T_1)_{CP} \quad (2.174)$$

Here  $A_1$  and  $A_3$  are the net absorption of solar radiation at the levels 1 and 3 (see Subsection G.1),  $R_4 - R_2$  and  $R_2 - R_0$  are the long-wave radiation absorbed in the layers 4-2 and 2-0 (see Subsections G.2 and G.3), and  $\Gamma$  is the sensible heat flux (see Subsection G.3). The  $(\Delta T)$  terms are the latent heat released during large-scale condensation (LS) [Eq. (2.47)], middle-level convection (CM) [Eqs. (2.73) and (2.74)], and penetrating convection (CP) [Eqs. (2.101) and (2.102)] (see Subsections F.2 and F.3). The factor  $5\Delta t$  is the time interval between heating calculations, and together with the factor  $2g/\pi c_p$  converts the heating rate to the layers' temperature change.

There is some smoothing of the heating as given by Eqs. (2.173) and (2.174) in both the vertical and horizontal directions before the temperatures  $T_1$  and  $T_3$  are redefined at the end of the time interval. The average heating,  $\bar{H} = 1/2(H_1 + H_3)$ , is first weighted according to the area of the grid cell surrounding the  $\pi$  point, and is then subjected to a 9-point areal smoothing with the central heating value weighted by 1/4, the four values to the north, south, east, and west each weighted by 1/8, and the four values to the northeast, northwest, southeast, and southwest each weighted by 1/16. If we denote the result of this smoothing operation on  $\bar{H}$  by  $\bar{H}^A$ , the final temperatures, after correction for diabatic heating at levels 1 and 3, are determined from

$$T_1 = T'_1 + \frac{H_1}{2} - \frac{H_3}{2} + \bar{H}^A \quad (2.175)$$

$$T_3 = T'_3 + \frac{H_3}{2} - \frac{H_1}{2} + \bar{H}^A \quad (2.176)$$

where  $T'_1$  and  $T'_3$  are the temperatures at levels 1 and 3 before the correction for diabatic heating.

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### III. MODEL DESCRIPTION -- NUMERICS

Equations (2.27) to (2.33) and Eq. (2.35) form a set of eight prognostic equations for the eight dependent variables ( $u_1, v_1, u_3, v_3, T_1, T_3, \pi$ , and  $q_3$ ). The time-extrapolation method and the horizontal finite-difference schemes used to solve these equations were developed by Professor Arakawa at UCLA and are discussed in the following sections. For convenience, Eqs. (2.27) to (2.33) and Eq. (2.35) have been restated in Tables 3.1 to 3.4 and Table 3.6, where the subsections describing the numerical treatment of each term are indicated, along with the location in the FORTRAN program where each term is evaluated. The diagnostic equation for the vertical velocity [Eq. (2.34)] is given a similar treatment in Table 3.5. In the present chapter, particular attention has been given to the preparation of a systematic statement of the precise finite-difference approximations actually used in the programmed numerical solution of the model. The smoothing procedures, provisions for global mass conservation, and the various parameters and constants used in the model are also summarized here.

#### A. TIME FINITE DIFFERENCES

##### 1. The General Scheme of Time Extrapolation

From the equations in Tables 3.1 to 3.4 and Table 3.6, we can obtain expressions for the tendencies of the dependent variables ( $\psi = u_1, v_1, \dots$ ) at the point  $ij$  in the general form

$$\left[ \frac{\partial (\Pi \psi)}{\partial t} \right]_{ij} = D_\psi + S_\psi \quad (3.1)$$

while the pressure-tendency equation is written in the form

$$\left[ \frac{\partial \Pi}{\partial t} \right]_{ij} = D_\pi \quad (3.2)$$

Table 3.1

## DESCRIPTION OF THE ZONAL (u) MOMENTUM EQUATIONS

-60-

	u Momentum Tendency	Horizontal Advection of u Momentum	Vertical Advection of u Momentum	Coriolis Force	Pressure-Gradient Force	Friction Term
Eq. (2.27):	$\frac{\partial}{\partial t} (\pi u_1) =$	$-\frac{\partial}{\partial x} (u_1^* u_1) - \frac{\partial}{\partial y} (v_1^* u_1)$	$-\dot{S}^u u_2$	$+ -v_1 F$	$-n \left[ \pi \frac{\partial \phi_1}{\partial x} + \sigma_1 \pi \alpha_1 \frac{\partial \pi}{\partial x} \right]$	$+ \pi F_1^x$
Eq. (2.29):	$\frac{\partial}{\partial t} (\pi u_3) =$	$-\frac{\partial}{\partial x} (u_3^* u_3) - \frac{\partial}{\partial y} (v_3^* u_3)$	$+\dot{S}^u u_2$	$+ -v_3 F$	$-n \left[ \pi \frac{\partial \phi_3}{\partial x} + \sigma_3 \pi \alpha_3 \frac{\partial \pi}{\partial x} \right]$	$+ \pi F_3^x$

Program Reference	STEP (1850-2280)	COMP 1 (4690-4830)	COMP 2 (5010-5200)	COMP 2 (5450-5690)	COMP 2 (5710-6050)	COMP 3 (11500-11620)
Text Reference	III.A. (1-4)	III.C.3	III.C.4	III.C.5	III.C.6	III.C.10



Table 3.2

## DESCRIPTION OF THE MERIDIONAL (v) MOMENTUM EQUATIONS

v Momentum Tendency		Horizontal Advection of v Momentum	Vertical Advection of v Momentum	Coriolis Force	Pressure-Gradient Force	Friction Term
Eq. (2.28):		$-\frac{\partial}{\partial x} (u_1 v_1^*) - \frac{\partial}{\partial y} (v_1 v_1^*)$	$-\dot{S}^u v_2$	$-\pi u_1 F$	$-m \left[ \pi \frac{\partial \phi_1}{\partial y} + \sigma_1 \pi \alpha_1 \frac{\partial \pi}{\partial y} \right]$	$+\pi F_1^y$
Eq. (2.30):		$-\frac{\partial}{\partial x} (u_3 v_3^*) - \frac{\partial}{\partial y} (v_3 v_3^*)$	$+\dot{S}^u v_2$	$-\pi u_3 F$	$-m \left[ \pi \frac{\partial \phi_3}{\partial y} + \sigma_3 \pi \alpha_3 \frac{\partial \pi}{\partial y} \right]$	$+\pi F_3^y$
Program Reference	STEP (1850-2280)	COMP 1 (3750-4120)	COMP 1 (4690-4830)	COMP 2 (5010-5200)	COMP 2 (5450-5690)	COMP 3 (11500-11620)
Text Reference	III.A. (1-4)	III.C.3	III.C.4	III.C.5	III.C.6	III.C.10

Table 3.3

## DESCRIPTION OF THE THERMODYNAMIC ENERGY EQUATION

Temperature Tendency	Horizontal Advection of Temperature	Energy Conversion Terms	Diabatic Heating Term
Eq. (2.31): $\frac{\partial}{\partial t} (\pi T_1) =$	$-\frac{\partial}{\partial x} (u_1^* T_1) - \frac{\partial}{\partial y} (v_1^* T_1)$	$-\left(\frac{p_1}{p_0}\right) \epsilon_2 \dot{s} + \frac{\sigma_1 \alpha_1}{c_p} \pi \frac{\partial \pi}{\partial t} + \frac{\sigma_1 \alpha_1}{c_p} [u_1^* \frac{\partial \pi}{\partial x} + v_1^* \frac{\partial \pi}{\partial y}]$	$+\pi \frac{\dot{H}_1}{c_p}$
Eq. (2.32): $\frac{\partial}{\partial t} (\pi T_3) =$	$-\frac{\partial}{\partial x} (u_3^* T_3) - \frac{\partial}{\partial y} (v_3^* T_3)$	$+\left(\frac{p_3}{p_0}\right) \epsilon_2 \dot{s} + \frac{\sigma_3 \alpha_3}{c_p} \pi \frac{\partial \pi}{\partial t} + \frac{\sigma_3 \alpha_3}{c_p} [u_3^* \frac{\partial \pi}{\partial x} + v_3^* \frac{\partial \pi}{\partial y}]$	$+\pi \frac{\dot{H}_3}{c_p}$
Program Reference	STEP (1850-2280)	COMP 1 (4560-4670)	COMP 2 (6070-6370) COMP 3 (11280-11480)
Text Reference	III.A.(1-4)	III.C.7	III.C.8 III.C.12

Table 3.4  
DESCRIPTION OF THE PRESSURE-TENDENCY EQUATION

	Pressure Tendency	Mass Convergence at the Upper Level	Mass Convergence at the Lower Level
Eq. (2.33):	$\frac{\partial \Pi}{\partial t} =$	$-\frac{1}{2} \left( \frac{\partial}{\partial x} u_1^* + \frac{\partial}{\partial y} v_1^* \right)$	$-\frac{1}{2} \left( \frac{\partial}{\partial x} u_3^* + \frac{\partial}{\partial y} v_3^* \right)$
Program Reference	STEP (1850-2280)	COMP 1 (4130-4540)	
Text Reference	III.A. (1-4)	III.C.2	

Table 3.5  
DESCRIPTION OF THE VERTICAL VELOCITY EQUATION

Vertical Velocity	Mass Convergence at Upper Level	Mass Convergence at Lower Level
Eq. (2.34):	$\dot{S} = + \frac{1}{2} \left( \frac{\partial}{\partial x} u_3^* + \frac{\partial}{\partial y} v_3^* \right)$	$- \frac{1}{2} \left( \frac{\partial}{\partial x} u_1^* + \frac{\partial}{\partial y} v_1^* \right)$
Program Reference	COMP 1 (4530)	COMP 1 (4130-4540)
Text Reference	III.C.2	III.C.2

Table 3.6

DESCRIPTION OF THE MOISTURE-BALANCE EQUATION

Moisture Tendency	Horizontal Advection of Moisture	Moisture-Source Term
Eq. (2.35): $\frac{\partial}{\partial t}(\Pi q_3) =$	$-\frac{\partial}{\partial x} \left[ q_3 \left( \frac{5}{4} u_3^* - \frac{1}{4} u_1^* \right) \right] - \frac{\partial}{\partial y} \left[ q_3 \left( \frac{5}{4} v_3^* - \frac{1}{4} v_1^* \right) \right]$	$+ 2mg(E - C)$
Program Reference STEP (1850-2280)	COMP 1 (3250-3730)	COMP 3 (11280-11480)
Text Reference III.A.(1-4)	III.C.9	III.C.11

The expression  $S_{\psi}$  represents the friction terms in the momentum equations, the diabatic heating term in the energy equation, or the moisture source term in the moisture equation. These terms will be referred to collectively as the "source terms." All the other terms are included in the expression  $D_{\psi}$ . Both  $D_{\psi}$  and  $S_{\psi}$  are complicated finite-difference expressions involving the independent variables and the dependent variables at  $ij$  and neighboring points.

In the time-extrapolation method used in this model, the source terms are evaluated every fifth time step. The remaining terms ( $D_{\psi}$ ) are evaluated each time step by means of a sequence of uncentered and centered horizontal differences. Thus, the time extrapolation proceeds in a repeated sequence of five individual time steps of  $\Delta t$  each. The first four time steps consist of two substages each, and the fifth time step consists of three substages. The first substage, which is identical in all five time steps, provides a preliminary estimate of the dependent variables for time  $\tau + n$  by evaluating  $D_{\psi}$  using values of the dependent variables at time  $\tau + (n - 1)$ . The second substage obtains a final estimate of the dependent variables using the preliminary estimates to evaluate  $D_{\psi}$  with the horizontal-difference scheme appropriate to the position in the five-step sequence. The special third substage in the fifth time step consists of evaluating the source terms using values of the dependent variables obtained from the second substage. An outline of this procedure is shown in Fig. 3.1, and each substage of the time step is described below.

## 2. Preliminary Estimate of the Dependent Variables (All Time Steps)

The preliminary estimate (identified in the FORTRAN code by the flag MRCH=1) is obtained using a forward time step and evaluating  $D_{\psi}$  by a centered horizontal difference. However, the horizontal and vertical advection terms and the Coriolis force term of  $D_{\psi}$  are advanced only a half time step, while the remaining terms are advanced a full time step ( $\Delta t$ ). Thus, from Eq. (3.1) for the momentum, energy, and moisture equations we have, upon omitting the source terms,

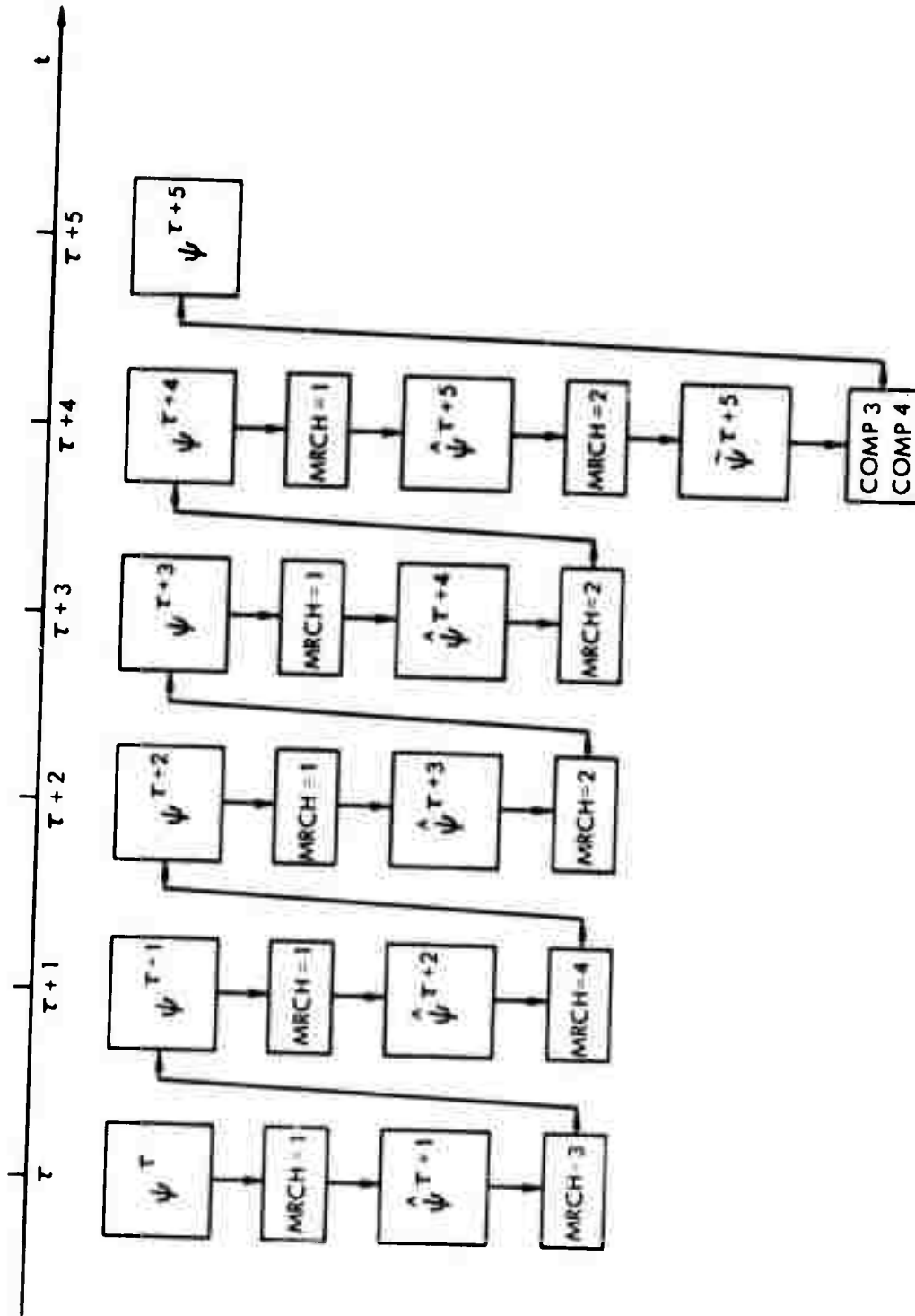


Fig. 3.1 -- Sequence of time steps and substages in the time-integration procedure.

$$(\hat{\Pi}\psi)_{ij}^{\tau+1} = (\Pi\psi)_{ij}^{\tau} + \frac{\Delta t}{2} A_{\psi}(\pi^{\tau}, u^{\tau}, \dots)_{ij} + \Delta t R_{\psi}(\pi^{\tau}, u^{\tau}, \dots)_{ij} \quad (3.3)$$

where  $A_{\psi}$  represents the advection terms in  $D_{\psi}$ ,  $R_{\psi} = D_{\psi} - A_{\psi}$  represents the remaining terms of  $D_{\psi}$ , the superscript  $\tau$  refers to values at time  $\tau$ , and the caret is used to indicate the preliminary estimate of a quantity. Similarly, the pressure-tendency equation (3.2) becomes

$$(\hat{\Pi})_{ij}^{\tau+1} = (\Pi)_{ij}^{\tau} + \Delta t D_{\pi}(\pi^{\tau}, u^{\tau}, \dots)_{ij} \quad (3.4)$$

The first estimate of the dependent variables  $\psi$  is therefore given by Eqs. (3.3) and (3.4) as

$$\hat{\psi}_{ij}^{\tau+1} = \frac{(\hat{\Pi}\psi)_{ij}^{\tau+1}}{\hat{\Pi}_{ij}^{\tau+1}} \quad (3.5)$$

which serves to remove the  $\Pi$  weighting of the variables. As noted previously, this procedure is used as a preliminary estimate in each time step of the numerical integration.

### 3. Final Estimate of the Dependent Variables (Time Steps 1 to 4)

Using the preliminary estimates given above, the final estimates of the dependent variables at the  $n$ th time step of the sequence  $n = 1, 2, 3, 4$  become

$$(\Pi\psi)_{ij}^{\tau+n} = (\Pi\psi)_{ij}^{\tau+(n-1)} + \Delta t D_{\psi}(\hat{\pi}, \hat{u}, \dots)_{ij} \quad (3.6)$$

$$\Pi_{ij}^{\tau+n} = \Pi_{ij}^{\tau+(n-1)} + \Delta t D_{\pi}(\hat{\pi}, \hat{u}, \dots)_{ij} \quad (3.7)$$

from which we calculate



$$\psi_{ij}^{\tau+n} = \frac{(\Pi\psi)_{ij}^{\tau+n}}{\Pi_{ij}^{\tau+n}} \quad (3.8)$$

When  $n = 1$  an up-right uncentered horizontal space difference is used (identified by the flag MRCH=3); when  $n = 2$ , a down-left uncentered horizontal space difference is used (identified by the flag MRCH=4), and when  $n = 3$  or 4, a centered horizontal space difference is used (identified by the flag MRCH=2). The case for  $n = 5$  is considered below.

#### 4. Final Estimate of the Dependent Variables (Time Step 5)

The first two substages of the fifth time step ( $n = 5$ ) are performed as described above by Eqs. (3.6) to (3.8). If we represent the variables at the end of the second substage of the fifth time step by a tilde, ( $\tilde{\phantom{x}}$ ), the final estimates become

$$(\psi)_{ij}^{\tau+5} = (\tilde{\psi})_{ij}^{\tau+5} + 5\Delta t \frac{S_{\psi}(\tilde{\pi}^{\tau+5}, u^{\tau+5}, \dots)_{ij}}{\tilde{\Pi}_{ij}^{\tau+5}} \quad (3.9)$$

The final estimate at every fifth time step thus introduces the source terms (as evaluated in subroutines COMP 3 and COMP 4), and weights them for the full  $5\Delta t$  time interval. Because the continuity (or pressure-tendency) equation (3.2) is source free, the value of  $\Pi_{ij}^{\tau+5}$  is given directly by the final estimate [Eq. (3.7)] for  $n = 5$ .

Upon the completion of this time step, the sequence of five steps begins again. The flow of this time-integration procedure is controlled by subroutine STEP (steps 1850 to 2280). The horizontal finite-difference expressions used in the determination of the terms  $S_{\psi}$ ,  $D_{\psi}$ , and  $R_{\psi}$  are given below.

## B. HORIZONTAL FINITE DIFFERENCES

### 1. The Horizontal Finite-Difference Grid

The earth's surface is represented in the numerical calculations by a rectangular grid of points extending from pole to pole, an arbitrary point of which is designated  $ij$  and identified by  $(J,I)$  in the code.<sup>†</sup> The 180th meridian is represented by the set of points  $(1,j)$ , the longitude 175W by the points  $(2,j)$ , etc., the South Pole by  $(1,1)$ , and the North Pole by  $(1,J)$ ; the equator is not a member of this grid, but corresponds to the value  $j = 23\frac{1}{2}$ . This set of primary grid points can be regarded as the centers of the network of rectangular cells outlined by dashed lines in Fig. (3.2). The velocity variables  $u$  and  $v$  are carried at the corners of the cells (designated by  $+$  in the figure), the west/east mass flux  $u^*$  at the midpoints of the vertical sides (designated  $>$ ), and the south/north mass flux  $v^*$  at the midpoint of the horizontal sides (designated  $\wedge$ ). All other quantities are carried at the midpoint of the cells (designated  $o$ ). The values of  $u$  and  $v$  at the lower right-hand corner of the cell  $(i,j)$  are denoted by  $u_{ij}$  and  $v_{ij}$ , the value of  $u^*$  on the right-hand side of the cell by  $u_{ij}^*$ , and the value of  $v^*$  on the lower side of the cell by  $v_{ij}^*$ . In the remainder of the text, the points  $o$ ,  $+$ ,  $>$ , and  $\wedge$  will be referred to as " $\pi$  points," " $u,v$  points," " $u^*$  points," and " $v^*$  points," respectively. It may be noted that the poles are " $\pi$  points," while the points at the equator are " $u,v$  points."

The grid-point separation factors  $m$  and  $n$  represent the geographical distance between grid points, and are defined by Eqs. (2.18) and (2.19). The factors  $m,n$  and the area ( $mn$ ) of the cells surrounding the  $\pi$  points are computed in subroutine MAGFAC (steps 14360 to 14850), where the following quantities are defined:

<sup>†</sup> For purposes of computational efficiency, the notation  $(J,I)$ , listing the y-index  $J$  first, is used in the FORTRAN code in lieu of the more conventional  $(I,J)$  notation. When reproducing specific FORTRAN statements this  $(J,I)$  notation, where  $J = 1, 2, \dots, JM$  and  $I = 1, 2, \dots, IM$ , will be used. Elsewhere, the notation  $(i,j)$ , where  $i = 1, 2, \dots, I$  and  $j = 1, 2, \dots, J$ , will be used.

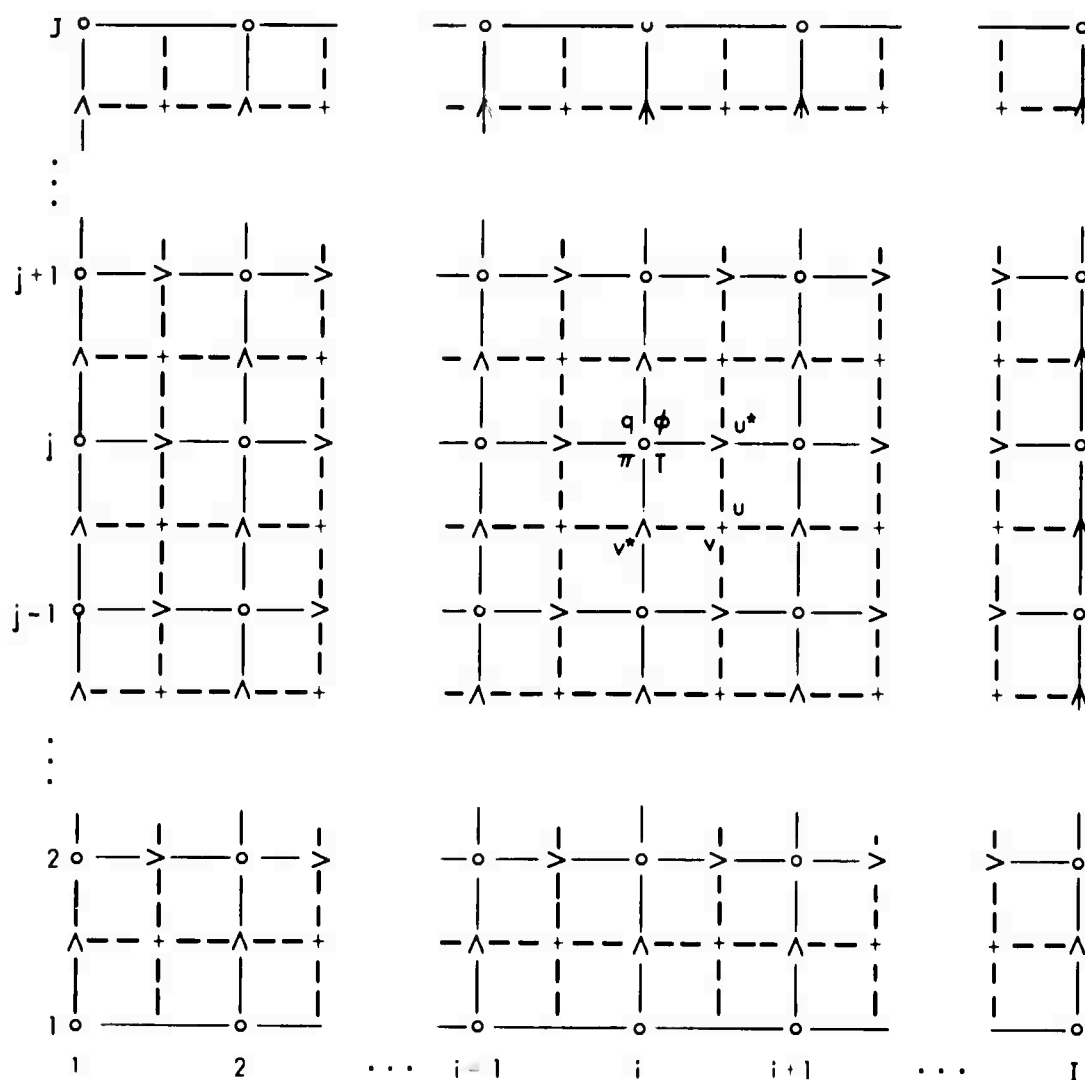


Fig. 3.2 -- The horizontal finite-difference grid with zonal index  $i$  and meridional index  $j$ . Here the open circles (o) represent grid points of the primary or  $\pi$  grid at which  $\pi$ ,  $T$ ,  $q$ , and  $\phi$  are carried, while the plus (+) signs represent points at which  $u$  and  $v$  are carried (the  $u,v$  grid). The carets ( $\wedge$  and  $>$ ) denote points of supplementary grids at which the northward and eastward mass fluxes  $v^*$  and  $u^*$  are determined.

$$\text{LAT}(j) = \varphi_j = \Delta\varphi(j - \frac{J+1}{2}) \quad 1 \leq j \leq J \quad (3.10)$$

$$\text{DXP}(j) = a\Delta\lambda \cos \varphi_j \quad 1 \leq j \leq J \quad (3.11)$$

$$\begin{aligned} \text{DXU}(j) &= a\Delta\lambda \frac{1}{2} (\cos \varphi_j + \cos \varphi_{j-1}) \\ &= \frac{1}{2} [\text{DXP}(j) + \text{DXP}(j-1)] \quad 1 \leq j \leq J \end{aligned} \quad (3.12)$$

$$\text{DYU}(j) = a(\varphi_j - \varphi_{j-1}) \quad j \geq 2 \quad (3.13)$$

$$\text{DYU}(1) = \text{DYU}(2)$$

$$\begin{aligned} \text{DYP}(j) &= a \frac{1}{2} (\varphi_{j+1} - \varphi_{j-1}) \\ &= \frac{1}{2} [\text{DYU}(j+1) + \text{DYU}(j)] \quad 2 \leq j \leq J \end{aligned} \quad (3.14)$$

$$\text{DYP}(1) = \text{DYU}(2)$$

$$\text{DYP}(J) = \text{DYU}(J)$$

$$\text{DXYP}(j) = \text{DYP}(j) \frac{[\text{DXU}(j+1) + \text{DXU}(j)]}{2} \quad 2 \leq j \leq J \quad (3.15)$$

$$\text{DXYP}(1) = \frac{1}{2} \text{DXU}(2) \frac{\text{DYP}(1)}{2}$$

$$\text{DXYP}(J) = \frac{1}{2} \text{DXU}(J) \frac{\text{DYP}(J)}{2}$$

These quantities are illustrated in Figs. 3.3 to 3.5. From Fig. 3.2 we see that  $\pi$  and  $u^*$  are carried at the same latitudes, whereas  $u$ ,  $v$ ,  $v^*$  are carried at intermediate latitudes. Thus, the factors  $m, n$  centered at  $\pi$  or  $u^*$  points are given by  $\text{DXP}$  and  $\text{DYP}$ , whereas those centered at  $u$ ,  $v$ , or  $v^*$  points are given by  $\text{DXU}$  and  $\text{DYU}$ . In this scheme the pressure ( $\pi$ ) is thus given at the poles but not at the equator, whereas the velocity ( $u, v$ ) is given at the equator but not at the poles.

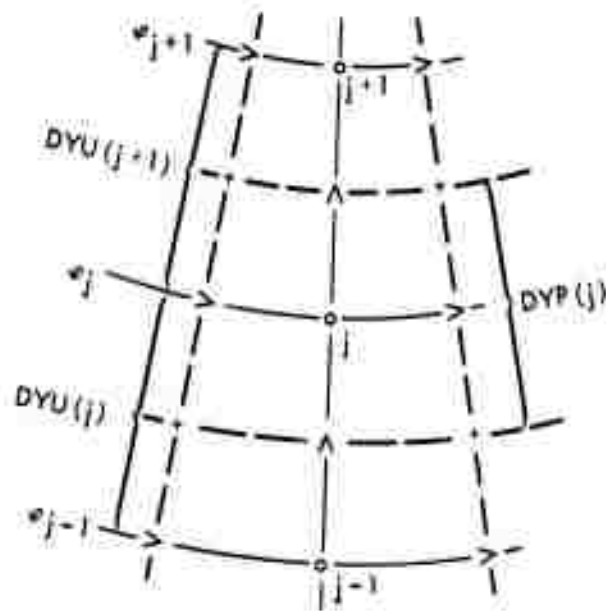


Fig. 3.3 -- The map metric  $n$ , the meridional distance between grid points. At latitude  $\varphi_j$ ,  $n = DYP$  is the north/south distance between points of the  $u,v$  grid (and between points of the  $v^*$  grid), while  $n = DYU$  gives the corresponding distance between points of the  $\pi$  grid (and between points of the  $u^*$  grid).

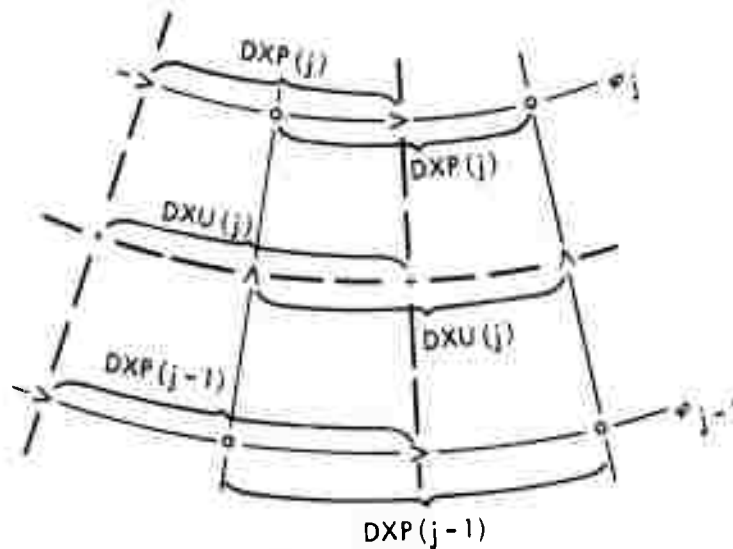


Fig. 3.4 -- The map metric  $m$ , the zonal distance between grid points. At latitude  $\varphi_j$ ,  $m = DXP$  is the east/west distance between points of the  $\pi$  grid (and between points of the  $u^*$  grid), while  $m = DXU$  gives the corresponding distance between points of the  $u,v$  grid (and between points of the  $v^*$  grid).

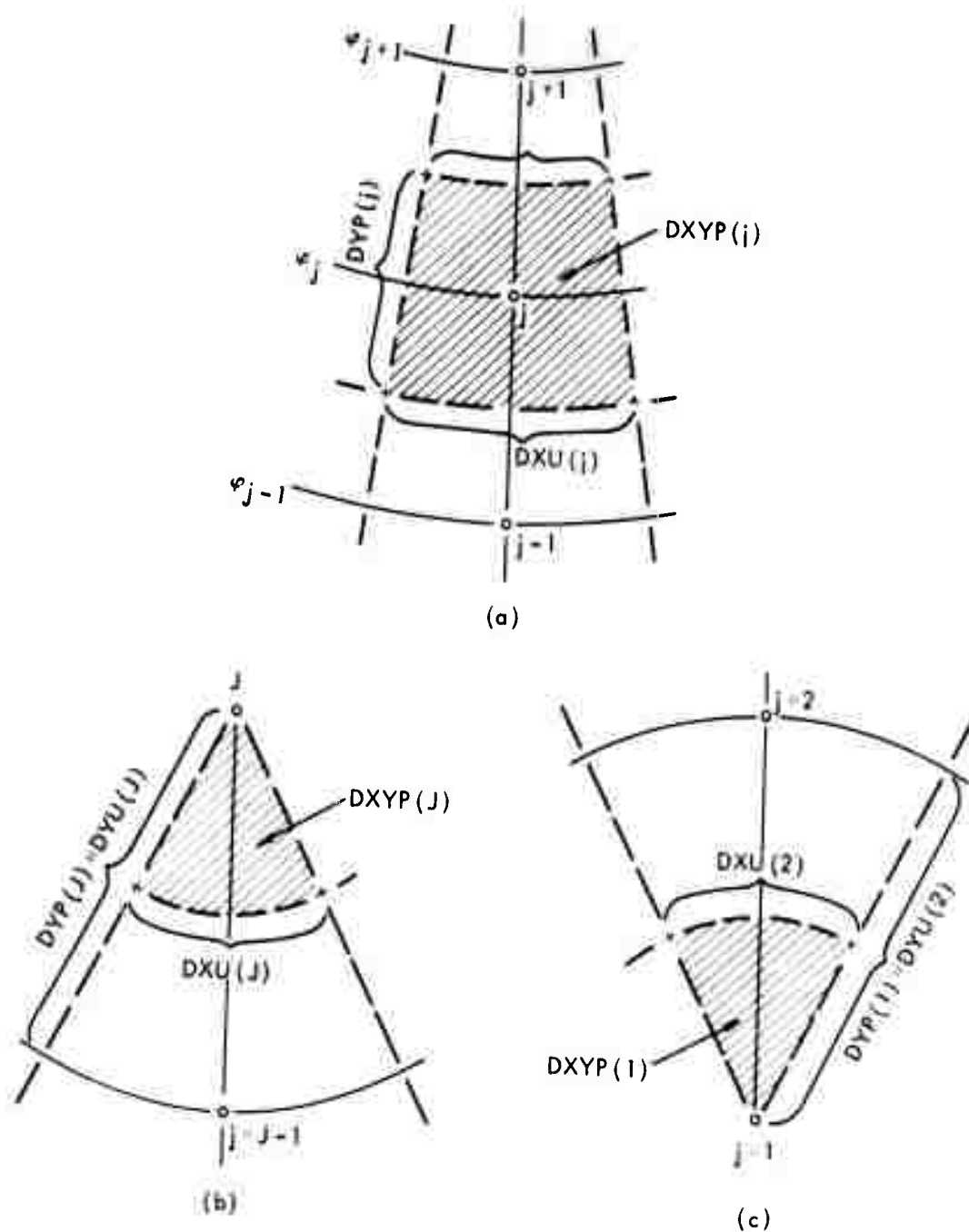


Fig. 3.5 -- The area  $mn = DXYP$  surrounding a point of the  $\pi$  grid (a). At the north and south poles ( $j=J$  and  $j=1$ ) this area is identified as the shaded regions shown in (b) and (c), respectively.

## 2. Finite-Difference Notation

The  $[J,I]$  indexing used in the FORTRAN code is identical for each of the four grid networks described above. That is,  $\pi_{JI}^*$ ,  $u_{JI}^*$  and  $v_{JI}^*$ ,  $u_{JI}^*$ , and  $v_{JI}^*$  all have the same index,  $(J,I)$ , but each of these is carried and computed at different points in the horizontal finite-difference grid. It is convenient, therefore, to define  $\pi^-$ ,  $u,v^-$ ,  $u^*$ -, and  $v^*$ -centered notations to be used in formulating the finite-difference expressions. These notations are illustrated in Figs. 3.6 to 3.9. Here the index used for the finite-difference expressions is given below each point, and the  $[J,I]$  index used in the FORTRAN code is given above each point. These figures facilitate the transformation of the finite-difference expressions given below into the equivalent FORTRAN statements found in the program itself (see Chapter VII).

It is also convenient to introduce a notation for the grid-point separation factors (the horizontal distances between grid points on the surface of the earth). For each of the  $\pi^-$ ,  $u,v^-$ ,  $u^*$ -, and  $v^*$ -centered notations (see Figs. 3.6 to 3.9),  $m_{-1}$ ,  $m_0$ , and  $m_1$  will denote the distance from -20 to 00, from -10 to 10, and from 00 to 02, respectively. Similarly,  $n_{-1}$ ,  $n_0$ , and  $n_1$  will denote the distance from 0-2 to 00, from 0-1 to 01, and from 00 to 02, respectively. The numerical values of  $m_0$ ,  $n_0$ , etc. are given in Eqs. (3.11) to (3.15). For example, when  $\pi^-$  or  $u^*$ -centered notation is used,  $m_0$  and  $m_{\pm 1}$  are given by  $DXP(j)$ ,  $n_0$  by  $DYP(j)$ ,  $n_{-1}$  by  $DYU(j)$ , and  $n_1$  by  $DYU(j+1)$ , whereas when  $u,v^-$  or  $v^*$ -centered notation is used,  $m_0$  and  $m_{\pm 1}$  are given by  $DXU(j)$ ,  $n_0$  by  $DYU(j)$ ,  $n_{-1}$  by  $DYP(j-1)$ , and  $n_1$  by  $DYP(j)$ .

In the following subsections, variables at the two vertical levels will be indicated by the subscript  $\ell$ , with  $\ell = 1$  denoting the (upper) level  $\sigma_1$  and  $\ell = 3$  denoting the (lower) level  $\sigma_3$ . In the FORTRAN code the index  $L$  is used to indicate the levels, with  $L = 1$  denoting the level  $\sigma_1$  and  $L = 2$  denoting the level  $\sigma_3$ .

## 3. Preparation for Time Extrapolation

At the beginning of each time step the dependent variables are transformed into a set of pressure-area-weighted variables. This trans-

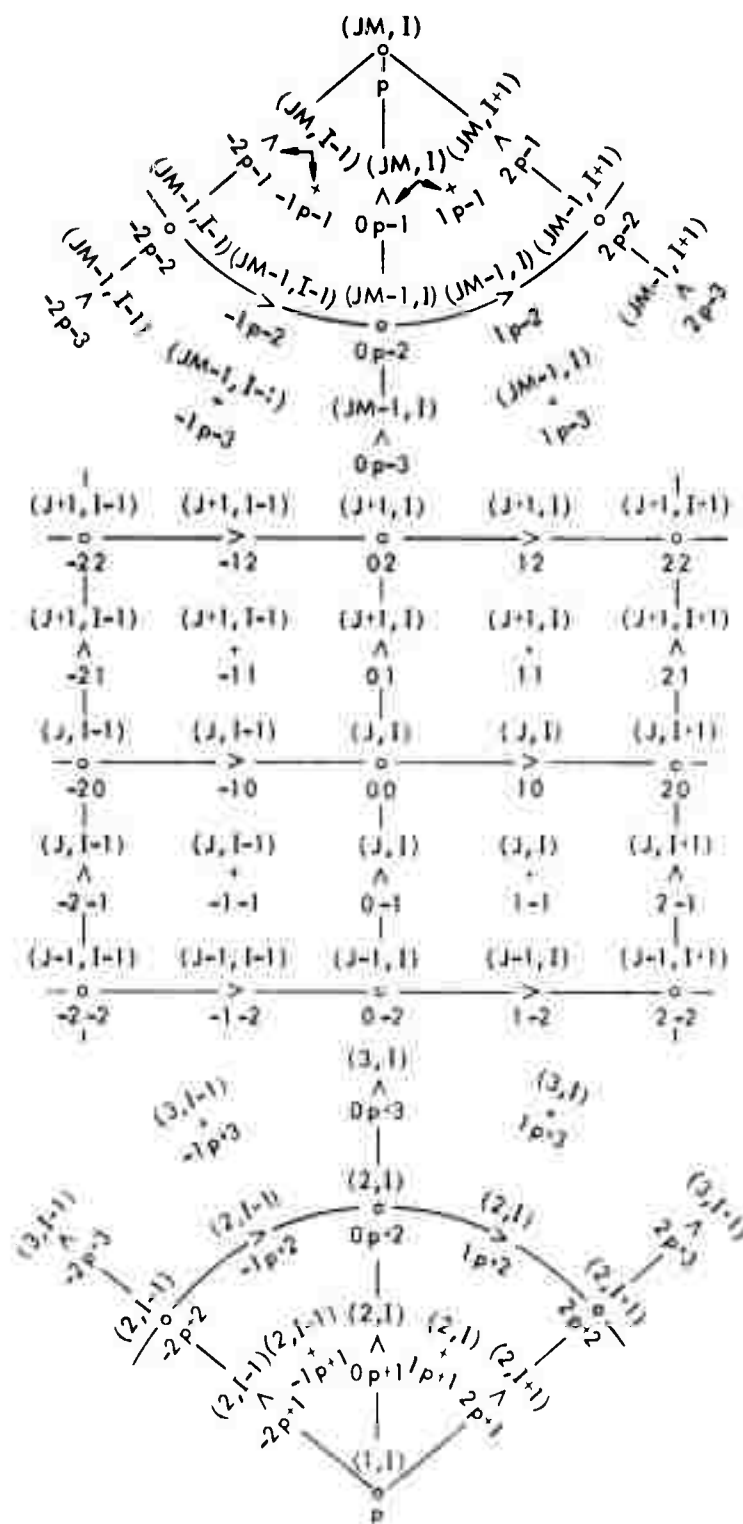


Fig. 3.6 -- The schematic finite-difference grid in  $\pi$ -centered notation. The symbols above each point are the FORTRAN J,I index, and those below each point are the finite-difference subscript notation relative to the origin 00 or relative to the poles (p). The open circles (o) are points of the  $\pi$  grid, the plus signs (+) are points of the u,v grid, and the carets (^ and >) are points of the  $v^*$  and  $u^*$  grids, respectively.



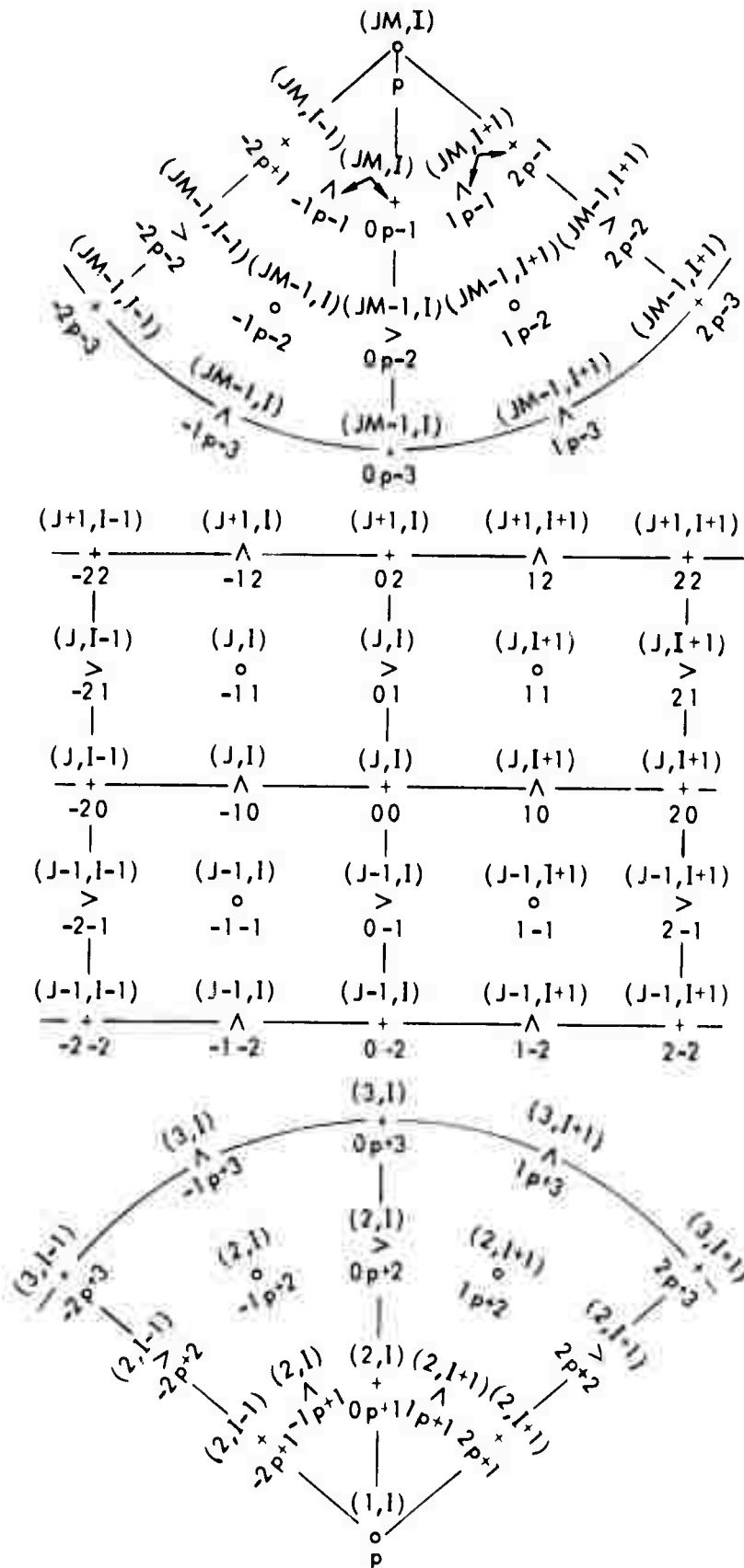


Fig. 3.7 -- The schematic finite-difference grid in  $u,v$ -centered notation. See Fig. 3.6 for symbol identification.

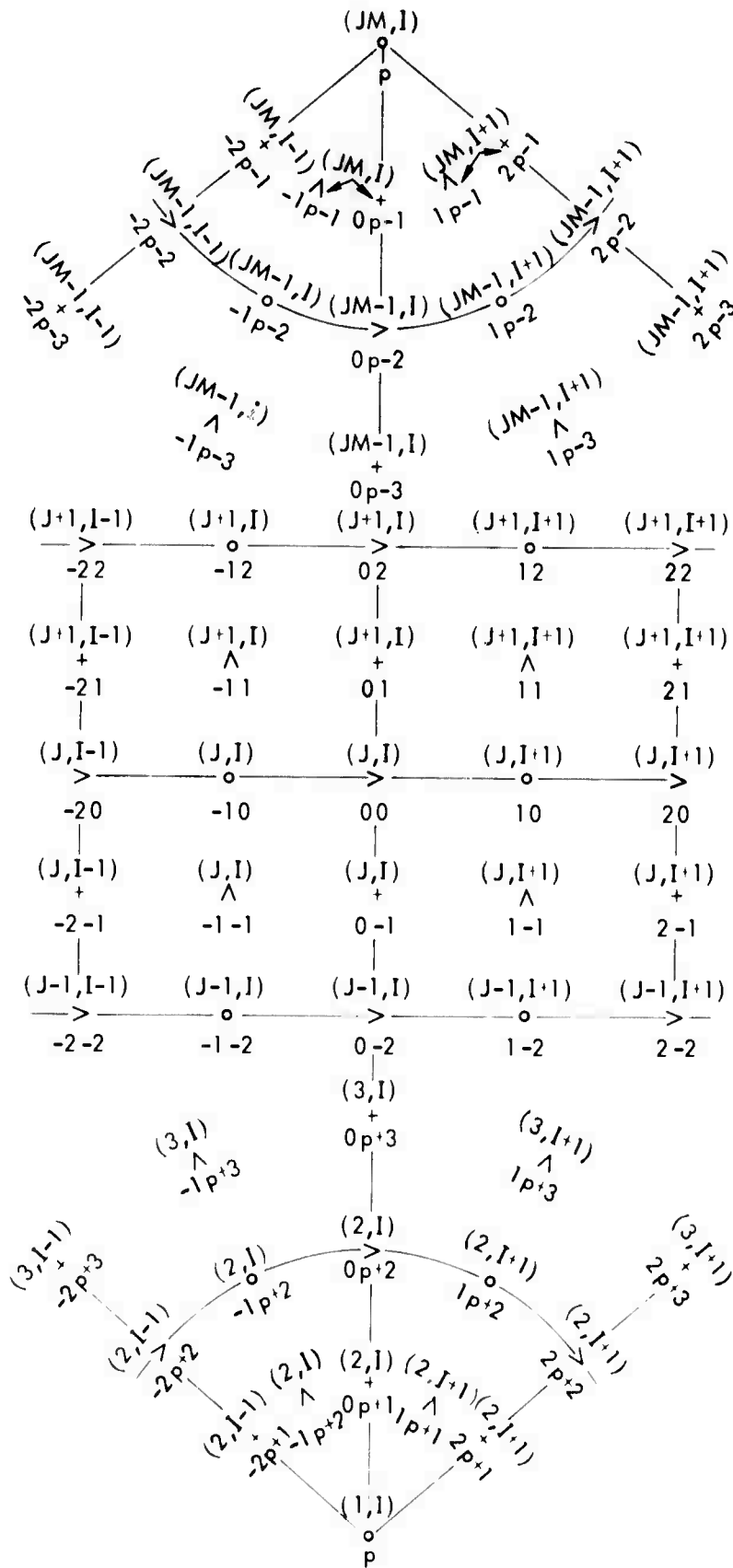


Fig. 3.8 -- The schematic finite-difference grid in  $u^*$ -centered notation. See Fig. 3.6 for symbol identification.

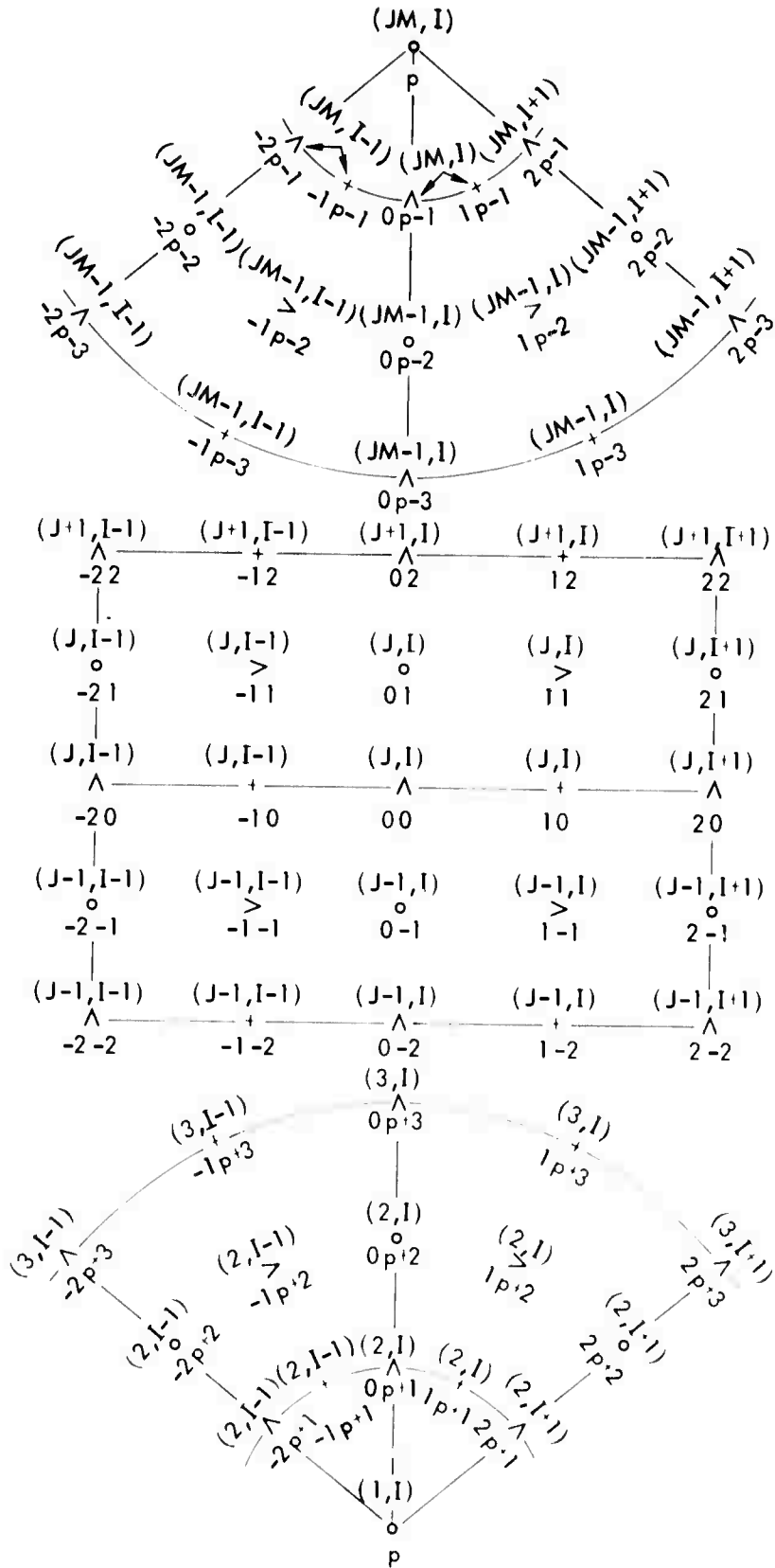


Fig. 3.9 -- The schematic finite-difference grid in v\*-centered notation. See Fig. 3.6 for symbol identification.

formation is performed at the beginning of subroutine COMP 1 (steps 2500 to 2680). For the quantities carried at  $\pi$  points ( $\pi$ ,  $\Pi$ ,  $T_3$ , and  $q_3$ ) the transformation is straightforward, and is given by

$$\Pi_{00} = (mn)_{00} \pi_{00} \quad (3.16)$$

$$(\Pi T)_{\ell,00} = (mn)_{00} \pi_{00} T_{\ell,00} \quad (3.17)$$

$$(\Pi q)_{3,00} = (mn)_{00} \pi_{00} q_{3,00} \quad (3.18)$$

where  $(mn)_{00}$  is the  $\pi$ -centered area  $DXYP(J)$  (see Fig. 3.5).

For the transformation of the velocity components we similarly write (in  $u,v$ -centered notation)

$$(\Pi u)_{\ell,00} = \Pi_{00}^u u_{\ell,00} \quad (3.19)$$

$$(\Pi v)_{\ell,00} = \Pi_{00}^u v_{\ell,00}$$

where the  $u,v$ -centered area-weighted  $\Pi$  is defined in  $u,v$ -centered notation as

$$\Pi_{00}^u = \frac{1}{4} \left[ (mn)_{-11} \pi_{-11} + (mn)_{11} \pi_{11} + (mn)_{-1-1} \pi_{-1-1} + (mn)_{1-1} \pi_{1-1} \right] \quad (3.20)$$

for  $2 < j \leq J - 1$

with the polar expressions

$$\Pi_{0,p+1}^u = \frac{1}{4} \left[ (mn)_{-1,p+2} \pi_{-1,p+2} + (mn)_{1,p+2} \pi_{1,p+2} \right] + (mn)_{i,1} \bar{\pi}_{i,1} \quad (3.21)$$

$$\Pi_{0,p-1}^u = \frac{1}{4} \left[ (mn)_{-1,p-2} \pi_{-1,p-2} + (mn)_{1,p-2} \pi_{1,p-2} \right] + (mn)_{i,J} \bar{\pi}_{i,J} \quad (3.22)$$

where p denotes the South or North Pole, and where

$$\bar{\pi}_{1,1} = \frac{1}{I} \sum_{i=1}^I \pi_{i,1} \quad (3.23)$$

and

$$\bar{\pi}_{1,J} = \frac{1}{I} \sum_{i=1}^I \pi_{i,J} \quad (3.24)$$

The quantities given by Eqs. (3.20) to (3.24) are illustrated in Fig. 3.10. Note that since the poles are mapped into I grid points, Eqs. (3.23) and (3.24) provide unique values of  $\pi$  for all I grid points of the South and North Poles. The other dependent variables carried at the poles ( $T_1$ ,  $T_3$ , and  $q_3$ ) and quantities computed at the poles, such as the mass convergence discussed in the next section, are similarly averaged. The polar adjustment of  $\pi$ ,  $T_1$ ,  $T_3$ , and  $q_3$  is performed in subroutine COMP 2 (steps 6410 to 6560).

### C. SOLUTION OF THE DIFFERENCE EQUATIONS

#### 1. The Mass Flux

The west/east and south/north mass fluxes are defined by Eqs. (2.25) and (2.26). These quantities require three finite-difference approximations corresponding to the three space-difference schemes (the up-right, down-left, and centered) used during the cycle of the time integration. Furthermore,  $u^*$  is given a longitudinal smoothing to avoid computational instability resulting from the decrease in the longitudinal spacing as the poles are approached. The mass-flux parameters are computed in subroutine COMP 1 (steps 2710 to 2950) and the longitudinal smoothing of  $u^*$  is performed in subroutine AVRX(K).

In the  $v^*$ -centered notation (see Fig. 3.9), the south/north mass flux  $v^*$  at the level  $l$  becomes

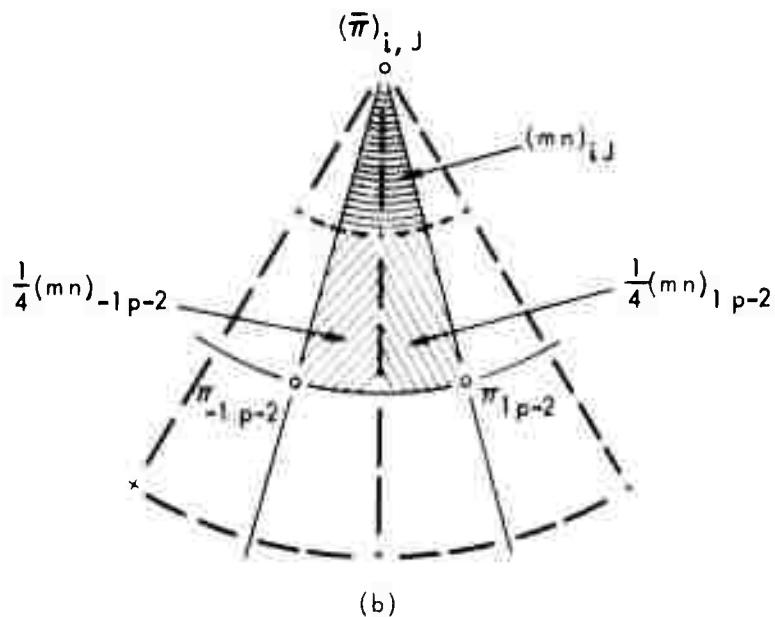
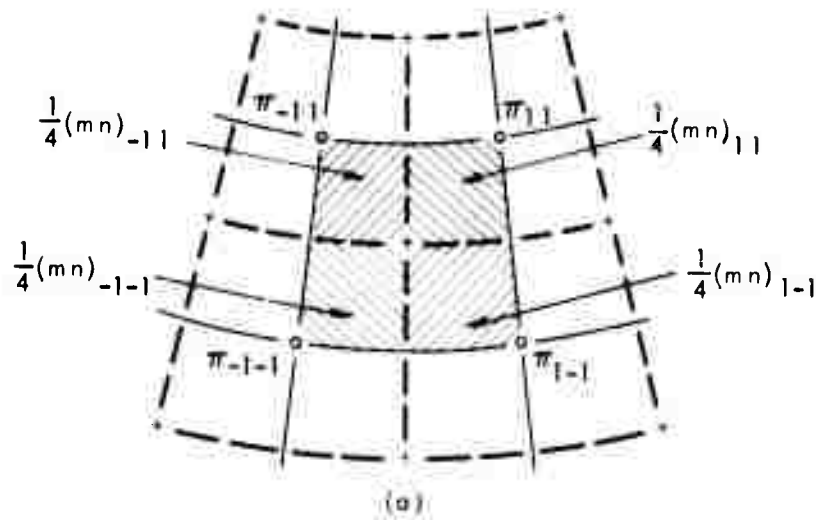


Fig. 3.10 -- Illustration of the area-pressure weighting function  $\Pi^u$  centered at  $u,v$  points. At non-polar points,  $\Pi^u$  is the sum of the four shaded areas shown in (a), each weighted by its adjacent value of  $\pi$ ; at polar points,  $\Pi^u$  is given by the sum of the three shaded areas shown in (b) weighted by the indicated values of  $\pi$ .

$$v_{\ell,00}^* = \left\{ \begin{array}{l} m_0 \frac{(v_{\ell,-10} + v_{\ell,10})}{2} \frac{(\pi_{01} + \pi_{0-1})}{2} \\ m_0 v_{\ell,10} \frac{(\pi_{01} + \pi_{0-1})}{2} \\ m_0 v_{\ell,-10} \frac{(\pi_{01} + \pi_{0-1})}{2} \end{array} \right\} \text{when } \left\{ \begin{array}{l} \text{MRCH} = 1 \text{ or } 2 \\ \text{MRCH} = 3 \\ \text{MRCH} = 4 \end{array} \right\} \quad (3.25)$$

The west/east mass flux  $u^*$  is computed in three stages. First,  $(nu)$  at the level  $\ell$  is computed according to

$$(nu)_{\ell,00} = \left\{ \begin{array}{l} \frac{n_1 u_{\ell,01} + n_{-1} u_{\ell,0-1}}{2} \\ n_1 u_{\ell,01} \\ n_{-1} u_{\ell,0-1} \end{array} \right\} \text{when } \left\{ \begin{array}{l} \text{MRCH} = 1 \text{ or } 2 \\ \text{MRCH} = 3 \\ \text{MRCH} = 4 \end{array} \right\} \quad (3.26)$$

where  $u^*$ -centered notation has been used (see Fig. 3.8). Second, the values of  $(nu)_{\ell,00}$  are smoothed in subroutine AVRX(K) using a three-point zonal smoothing routine that may be represented by

$$(\overline{nu})_{\ell,00} = \lambda_0 (nu)_{\ell,-10} + (1 - 2\lambda_0) (nu)_{\ell,00} + \lambda_0 (nu)_{\ell,10} \quad (3.27)$$

where  $\lambda_0$  is the weighting factor of the smoothing routine. This smoothing procedure is described further in Section D below. After this calculation, the west/east mass flux  $u^*$  at the level  $\ell$  is finally computed from

$$u_{\ell,00}^* = (\overline{nu})_{\ell,00}^{N_0} \frac{(\pi_{-10} + \pi_{10})}{2} \quad (3.28)$$

where the superscript  $N_0$  denotes the smoothed result after application of the subroutine AVRX(K)  $N_0$  times (see Section D).

At this point it should be noted that  $u^*$  at the poles ( $u_{1,1}^*$  and  $u_{1J}^*$ ) has no meaning. However, to determine the advection of momentum in the polar caps, an equivalent  $u^*$  at the poles is defined. The routine used to compute this equivalent polar  $u^*$  is described in Subsection C.3 below.

## 2. Continuity Equation

The prognostic equation (2.33) for the pressure tendency and the diagnostic equation (2.34) for the vertical-velocity term may be rewritten in terms of the mass convergence at levels 1 and 3. Thus,

$$\frac{\partial \pi}{\partial \tau} = -\frac{1}{2} \left( \frac{\partial u_1^*}{\partial x} + \frac{\partial v_1^*}{\partial y} \right) - \frac{1}{2} \left( \frac{\partial u_3^*}{\partial x} + \frac{\partial v_3^*}{\partial y} \right) \quad (3.29)$$

$$\dot{S} = -\frac{1}{2} \left( \frac{\partial u_1^*}{\partial x} + \frac{\partial v_1^*}{\partial y} \right) + \frac{1}{2} \left( \frac{\partial u_3^*}{\partial x} + \frac{\partial v_3^*}{\partial y} \right) \quad (3.30)$$

In the  $\pi$ -centered notation (see Fig. 3.6), the mass convergence at all grid points, except the poles, is given by

$$\begin{aligned} \left( \frac{\partial u_l^*}{\partial x} + \frac{\partial v_l^*}{\partial y} \right)_{l,00} &= \text{CONV}_{l,00} \\ &= (u_{l,10}^* - u_{l,-10}^*) + (v_{l,01}^* - v_{l,0-1}^*) \\ 2 \leq j \leq J-1 \end{aligned} \quad (3.31)$$

Only the south/north mass flux ( $v^*$ ) contributes to the total mass convergence within the polar cap. The total mass convergence at the South and North Poles is therefore given by

$$\text{CONV}_{l,1} = \sum_{i=1}^I v_{l,i,p+1}^* \quad (3.32)$$



$$\text{CONV}_{\ell,J} = - \sum_{i=1}^I v_{\ell,i,p-1}^* \quad (3.33)$$

while the mass convergence attributed to each of the  $I$  sectors of the polar caps is given by

$$\text{CONV}_{\ell,i,1} = \frac{1}{I} \sum_{i=1}^I v_{\ell,p+1}^* \quad (3.34)$$

$$\text{CONV}_{\ell,i,J} = \frac{1}{I} \sum_{i=1}^I v_{\ell,i,p-1}^* \quad (3.35)$$

Thus, Eqs. (3.29) and (3.30) may be written in the computational forms

$$\left( \frac{\partial \Pi}{\partial t} \right)_{00} = - \frac{1}{2} (\text{CONV}_{1,00} + \text{CONV}_{3,00}) \quad (3.36)$$

$$\dot{s}_{00} = \frac{1}{2} (\text{CONV}_{3,00} - \text{CONV}_{1,00}) \quad (3.37)$$

for an arbitrary point outside the polar cap,

$$\left( \frac{\partial \Pi}{\partial t} \right)_{i,1} = - \frac{1}{2} (\text{CONV}_{1,i,1} + \text{CONV}_{3,i,1}) \quad (3.38)$$

$$\dot{s}_{i,1} = \frac{1}{2} (\text{CONV}_{3,i,1} - \text{CONV}_{1,i,1}) \quad (3.39)$$

at the South Pole, and

$$\left( \frac{\partial \Pi}{\partial t} \right)_{i,J} = - \frac{1}{2} (\text{CONV}_{1,i,J} + \text{CONV}_{3,i,J}) \quad (3.40)$$

$$\dot{s}_{i,J} = \frac{1}{2} (\text{CONV}_{3,i,J} - \text{CONV}_{1,i,J}) \quad (3.41)$$

at the North Pole.

### 3. Horizontal Advection of Momentum

The horizontal advection of momentum at the  $u, v$ -grid point  $i, j$  and at the level  $l$  is approximated in the equations of motion (2.27) to (2.30) by

$$\left[ \frac{\partial}{\partial x} (u^* u) + \frac{\partial}{\partial y} (v^* u) \right]_{l, i, j} \approx \oint_{\Gamma} u \vec{U}^* \cdot \vec{N} d\Gamma \quad (3.42)$$

and

$$\left[ \frac{\partial}{\partial x} (u^* v) + \frac{\partial}{\partial y} (v^* v) \right]_{l, i, j} \approx \oint_{\Gamma} v \vec{U}^* \cdot \vec{N} d\Gamma \quad (3.43)$$

where  $\vec{U}^*$  is a vector in the  $x, y$  plane with  $u^*$  and  $v^*$  as its  $x$  and  $y$  components, and  $\vec{N}$  is the outward unit vector normal to the contour  $\Gamma$  of the rectangular grid defined by the four  $\pi$  points surrounding the  $u$ -grid point  $i, j$  (see Fig. 3.11).

To evaluate the integrals in Eqs. (3.42) and (3.43) the contour  $\Gamma$  is divided into eight segments. Along each of the eight segments,  $\vec{U}^* \cdot \vec{N}$  is defined (using  $u, v$ -centered notation) as

$$\begin{aligned} U_{10} &= \frac{2}{3} \cdot \frac{1}{4} [u_{01}^* + u_{21}^* + u_{2-1}^* + u_{0-1}^*], & \text{along ab} \\ \tilde{U}_{11} &= \frac{1}{6} \cdot \frac{1}{2} [u_{01}^* + u_{21}^*] + \frac{1}{6} \cdot \frac{1}{2} [v_{10}^* + v_{12}^*], & \text{along bc} \\ V_{01} &= \frac{2}{3} \cdot \frac{1}{4} [v_{10}^* + v_{12}^* + v_{-12}^* + v_{-10}^*], & \text{along cd} \\ \tilde{V}_{-11} &= \frac{1}{6} \cdot \frac{1}{2} [v_{-10}^* + v_{-12}^*] - \frac{1}{6} \cdot \frac{1}{2} [u_{01}^* + u_{-21}^*], & \text{along de} \\ -U_{-10} &= -\frac{2}{3} \cdot \frac{1}{4} [u_{01}^* + u_{-21}^* + u_{-2-1}^* + u_{0-1}^*], & \text{along ef} \\ -\tilde{U}_{-1-1} &= -\frac{1}{6} \cdot \frac{1}{2} [u_{0-1}^* + u_{-2-1}^*] - \frac{1}{6} \cdot \frac{1}{2} [v_{-10}^* + v_{-1-2}^*], & \text{along fg} \\ -V_{0-1} &= -\frac{2}{3} \cdot \frac{1}{4} [v_{10}^* + v_{1-2}^* + v_{-1-2}^* + v_{-10}^*], & \text{along gh} \\ -\tilde{V}_{1-1} &= -\frac{1}{6} \cdot \frac{1}{2} [v_{10}^* + v_{1-2}^*] + \frac{1}{6} \cdot \frac{1}{2} [u_{0-1}^* + u_{2-1}^*], & \text{along ha} \end{aligned} \quad (3.44)$$

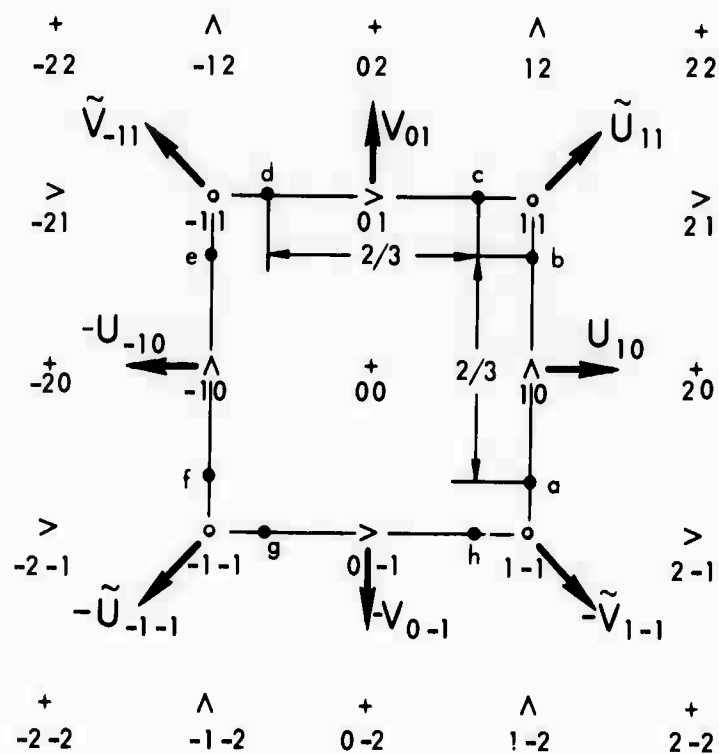


Fig. 3.11 -- Schematic representation of the fluxes  $U, V$  and  $\tilde{U}, \tilde{V}$  on the grid cell surrounding a point of the  $u, v$  grid (identified by 00 in  $u, v$  notation; see Fig. 3.7).

With these definitions, Eqs. (3.42) and (3.43) become

$$\begin{aligned} \left[ \frac{\partial}{\partial x} (u^* u) + \frac{\partial}{\partial y} (v^* u) \right]_{00} = & \frac{1}{2} \left[ U_{10}(u_{00} + u_{20}) - U_{-10}(u_{-20} + u_{00}) \right. \\ & + V_{01}(u_{00} + u_{02}) - V_{0-1}(u_{0-2} + u_{00}) + \tilde{U}_{11}(u_{00} + u_{20}) \\ & - \tilde{U}_{-1-1}(u_{-2-2} + u_{00}) + \tilde{V}_{-11}(u_{00} + u_{-22}) \\ & \left. - \tilde{V}_{1-1}(u_{2-2} + u_{00}) \right] \end{aligned} \quad (3.45)$$

$$\begin{aligned} \left[ \frac{\partial}{\partial x} (u^* v) + \frac{\partial}{\partial y} (v^* v) \right]_{00} = & \frac{1}{2} \left[ U_{10}(v_{00} + v_{20}) - U_{-10}(v_{-20} + v_{00}) \right. \\ & + V_{01}(v_{00} + v_{02}) - V_{0-1}(v_{0-2} + v_{00}) + \tilde{U}_{11}(v_{00} + v_{20}) \\ & \left. - \tilde{U}_{-1-1}(v_{-2-2} + v_{00}) + \tilde{V}_{-11}(v_{00} + v_{-22}) - \tilde{V}_{1-1}(v_{2-2} + v_{00}) \right] \end{aligned} \quad (3.46)$$

at all points outside the polar cap. In Eqs. (3.44) to (3.46) the subscript  $l$  has been dropped, and it should be understood that these expressions for the horizontal advection are valid for  $l = 1$  and  $3$ .

The momentum advection within the polar cap requires special treatment. In Fig. 3.11 it can be seen that when the unit square represents a north polar sector, the fluxes  $\tilde{V}_{-11}$ ,  $V_{01}$ , and  $\tilde{U}_{11}$  represent advection across the pole. Physically, advection can occur across the pole only from a single sector to that sector separated by 180 deg of longitude. Thus, transpolar advection is not calculated and  $\tilde{V}_{-11}$ ,  $V_{01}$  and  $\tilde{U}_{11}$  are not defined. However, the fluxes  $U_{-10}$  and  $U_{10}$  represent advection between adjacent sectors within the polar cap, but the definitions for these fluxes [Eq. (3.44)] break down since  $u^*$  is not defined at the poles. To circumvent this, a polar  $u^*$  is determined in subroutine COMP 1 (steps 2790 to 3230) so that the near-polar  $U$  are given by

$$U_{\pm 1, p-1} = \frac{1}{6} \left( u_{0, J}^* + u_{\pm 2, J}^* + u_{0, p-2}^* + u_{\pm 2, p-2}^* \right) \quad (3.47)$$

and the continuity equation

$$\begin{aligned} \frac{\partial}{\partial t} (\Pi_{0,p-1}^u) + U_{1,p-1} - U_{-1,p-1} - V_{0,p-2} \\ - \tilde{U}_{-1,p-2} - \tilde{V}_{1,p-2} - \dot{S}_{0,p-1}^u = 0 \end{aligned} \quad (3.48)$$

is satisfied for each of the north polar sectors. Here u,v-centered notation has been used, and the definition of  $\dot{S}_{0,p-1}^u$  is given in the next subsection.

It is shown by Langlois and Kwok (1969) that under the above conditions  $u^*$  at a polar grid point i,J is given by

$$u_{i,J}^* = 3 \left( \psi_i - \frac{1}{I} \sum_{i=1}^I \psi_i \right) \quad (3.49)$$

where  $\psi_i$  is given by

$$\begin{aligned} \psi_1 = 0, \psi_2 = v_{3/2}^{*'}, \psi_3 = v_{3/2}^{*'} + v_{5/2}^{*'}, \dots, \psi_i = \sum_{k=1}^{i-1} v_{k+1/2}^{*'}; \\ i = 2, 3, \dots, I \end{aligned} \quad (3.50)$$

and

$$v_{i+1/2}^{*'} = v_{i+1/2,p-1}^* - \frac{1}{I} \sum_{i=0}^{I-1} v_{i+1/2,p-1}^* \quad (3.51)$$

In Eqs. (3.50) and (3.51) the fractional values of the index i are used to denote the  $v^*$ -grid points to the right of the u,v-grid point (i,p-1). Similar expressions can be derived for the South Pole.

If we use Eqs. (3.49) to (3.51) to determine the values of  $u_{0,J}^*$  and  $u_{\pm 2,J}^*$  in Eq. (3.47), the polar horizontal advection of momentum in u,v-centered notation becomes

$$\begin{aligned} \left[ \frac{\partial}{\partial x} (u^* u) + \frac{\partial}{\partial y} (v^* u) \right]_{0,p+1} = & \frac{1}{2} \left[ u_{1,p+1}(u_{0,p+1} + u_{2,p+1}) \right. \\ & - u_{-1,p+1}(u_{-2,p+1} + u_{0,p+1}) + v_{0,p+2}(u_{0,p+1} + u_{0,p+3}) \\ & \left. + \tilde{u}_{1,p+2}(u_{0,p+1} + u_{2,p+3}) + \tilde{v}_{-1,p+2}(u_{0,p+1} + u_{-2,p+3}) \right] \quad (3.52) \end{aligned}$$

and

$$\begin{aligned} \left[ \frac{\partial}{\partial x} (u^* v) + \frac{\partial}{\partial y} (v^* v) \right]_{0,p+1} = & \frac{1}{2} \left[ u_{1,p+1}(v_{0,p+1} + v_{2,p+1}) \right. \\ & - u_{-1,p+1}(v_{-2,p+1} + v_{0,p+1}) + v_{0,p+2}(v_{0,p+1} + v_{0,p+3}) \\ & \left. + \tilde{u}_{1,p+2}(v_{0,p+1} + v_{2,p+3}) + \tilde{v}_{-1,p+2}(v_{0,p+1} + v_{-2,p+3}) \right] \quad (3.53) \end{aligned}$$

at the South Pole, and

$$\begin{aligned} \left[ \frac{\partial}{\partial x} (u^* u) + \frac{\partial}{\partial y} (v^* u) \right]_{0,p-1} = & \frac{1}{2} \left[ u_{1,p-1}(u_{0,p-1} + u_{2,p-1}) \right. \\ & - u_{-1,p-1}(u_{-2,p-1} + u_{0,p-1}) - v_{0,p-2}(u_{0,p-3} + u_{0,p-1}) \\ & \left. - \tilde{u}_{-1,p-2}(u_{-2,p-3} + u_{0,p-1}) - \tilde{v}_{1,p-2}(u_{2,p-3} + u_{0,p-1}) \right] \quad (3.54) \end{aligned}$$

and

$$\begin{aligned} \left[ \frac{\partial}{\partial x} (u^* v) + \frac{\partial}{\partial y} (v^* v) \right]_{0,p-1} = & \frac{1}{2} \left[ u_{1,p-1}(v_{0,p-1} + v_{2,p-1}) \right. \\ & - u_{-1,p-1}(v_{-2,p-1} + v_{0,p-1}) - v_{0,p-2}(v_{0,p-3} + v_{0,p-1}) \\ & \left. - \tilde{u}_{-1,p-2}(v_{-2,p-3} + v_{0,p-1}) - \tilde{v}_{1,p-2}(v_{2,p-3} + v_{0,p-1}) \right] \quad (3.55) \end{aligned}$$

at the North Pole.

#### 4. Vertical Advection of Momentum

In Subsection C.2 the vertical velocity parameter  $\dot{S}$  is defined at  $\pi$ -grid points [Eqs. (3.37), (3.39), and (3.41)]. However, for use in the momentum equations, a  $\dot{S}^u$ , analogous to  $\Pi^u$  [Eqs. (3.20) to (3.24)] must be defined at u,v-grid points. Thus, at u,v points outside the polar cap the vertical advection term in u,v-centered notation is given by

$$\frac{(u_{1,00} + u_{3,00})}{2} \dot{S}_{00}^u = u_{2,00} \frac{1}{4} (\dot{S}_{-11} + \dot{S}_{11} + \dot{S}_{1-1} + \dot{S}_{-1-1}) \quad (3.56)$$

and at the poles by

$$\frac{(u_{1,0,p+1} + u_{3,0,p+1})}{2} \dot{S}_{0,p+1}^u = u_{2,0,p+1} \left[ \frac{1}{4} (\dot{S}_{-1,p+2} + \dot{S}_{1,p+2}) + \bar{\dot{S}}_{1,1} \right] \quad (3.57)$$

and

$$\frac{(u_{1,0,p-1} + u_{3,0,p-1})}{2} \dot{S}_{0,p-1}^u = u_{2,0,p-1} \left[ \frac{1}{4} (\dot{S}_{-1,p-2} + \dot{S}_{1,p-2}) + \bar{\dot{S}}_{1,J} \right] \quad (3.58)$$

where

$$\bar{\dot{S}}_{1,1} = \frac{1}{I} \sum_{i=1}^I \dot{S}_{i,1} \quad (3.59)$$

and

$$\bar{\dot{S}}_{1,J} = \frac{1}{I} \sum_{i=1}^I \dot{S}_{i,J} \quad (3.60)$$

## 5. Coriolis Force

To evaluate the Coriolis force term in the momentum equations, the parameter  $F$  [Eq. (2.24)] and the Coriolis parameter  $f = 2\Omega \sin \varphi$  are the first obtained at the  $\pi$ -grid points. The Coriolis parameter is computed in subroutine MAGFAC (steps 14710 to 14750). In terms of  $\pi$ -centered notation it is defined as

$$f_{00} = \Omega \frac{a}{2(mn)_{00}} \left[ (\cos \varphi_{-2} + \cos \varphi_0) m_{-1} - (\cos \varphi_0 + \cos \varphi_2) m_1 \right] \quad (3.61)$$

Equation (3.61) can be reduced to

$$f_{00} = -2\Omega \frac{\cos \varphi_2 - \cos \varphi_{-2}}{\varphi_2 - \varphi_{-2}}$$

which is a finite-difference analog of

$$f = 2\Omega \sin \varphi = -2\Omega \frac{\partial (\cos \varphi)}{\partial \varphi}$$

At the poles  $f$  is given by

$$f_J = \Omega \frac{a}{(mn)_J} \left[ (\cos \varphi_J + \cos \varphi_{J-1}) m_J \right] \quad (3.62)$$

and

$$f_1 = -f_J \quad (3.63)$$



With the Coriolis parameter defined by Eqs. (3.61) to (3.63), the finite-difference form of Eq. (2.24) in  $\pi$ -centered notation becomes

$$F_{00} = (m\pi)_{00} f_{00} - \frac{1}{4} (u_{-11} + u_{11} + u_{1-1} + u_{-1-1})(m_1 - m_{-1}) \quad (3.64)$$

Finally, the Coriolis term at a  $u,v$ -grid point is represented in terms of  $F$  at the four surrounding  $\pi$  points by

$$\begin{aligned} (u\pi F)_{\ell,00} = \frac{1}{2} & \left[ \frac{(\pi_{11} + \pi_{1-1})}{2} \frac{(F_{11} + F_{1-1})}{2} \right. \\ & \left. + \frac{(\pi_{-11} + \pi_{-1-1})}{2} \frac{(F_{-11} + F_{-1-1})}{2} \right] u_{\ell,00} \end{aligned} \quad (3.65)$$

$$\begin{aligned} (v\pi F)_{\ell,00} = \frac{1}{2} & \left[ \frac{(\pi_{11} + \pi_{1-1})}{2} \frac{(F_{11} + F_{1-1})}{2} \right. \\ & \left. + \frac{(\pi_{-11} + \pi_{-1-1})}{2} \frac{(F_{-11} + F_{-1-1})}{2} \right] v_{\ell,00} \end{aligned} \quad (3.66)$$

where  $u,v$ -centered notation has been used.

## 6. Pressure-Gradient Force

The pressure-gradient force terms require a treatment analogous to that for the mass flux discussed in Subsection C.1. That is, they require three finite-difference approximations corresponding to the three space-difference schemes used during the cycle of the time integration, and the pressure-gradient terms of the  $u$ -momentum equation are smoothed using subroutine AVRX(K), as discussed in Subsection C.1.

In  $u,v$ -centered notation, the pressure-gradient force in the  $u$ -momentum equation [Eqs. (2.27) and (2.29)] is given by

$$n_0 \left( \pi \frac{\partial \phi_\ell}{\partial x} + \sigma_\ell \pi \alpha_\ell \frac{\partial \pi}{\partial x} \right)_{\ell,00}$$

$$= \frac{n_0}{4} \frac{\{(\pi_{-11} + \pi_{11})(\phi_{\ell,11} - \phi_{\ell,-11}) + [(\sigma_\ell \pi \alpha_\ell)_{-11} + (\sigma_\ell \pi \alpha_\ell)_{11}](\pi_{11} - \pi_{-11})\}^{N_0}}{+ \frac{n_0}{4} \frac{\{(\pi_{-1-1} + \pi_{1-1})(\phi_{\ell,1-1} - \phi_{\ell,-1-1}) + [(\sigma_\ell \pi \alpha_\ell)_{-1-1} + (\sigma_\ell \pi \alpha_\ell)_{1-1}](\pi_{1-1} - \pi_{-1-1})\}^{N_0}}$$

when MRCH = 1 or 2

$$= \frac{n_0}{2} \frac{\{(\pi_{-11} + \pi_{11})(\phi_{\ell,11} - \phi_{\ell,-11}) + [(\sigma_\ell \pi \alpha_\ell)_{-11} + (\sigma_\ell \pi \alpha_\ell)_{11}](\pi_{11} - \pi_{-11})\}^{N_0}}$$

when MRCH = 3

$$= \frac{n_0}{2} \frac{\{(\pi_{-1-1} + \pi_{1-1})(\phi_{\ell,1-1} - \phi_{\ell,-1-1}) + [(\sigma_\ell \pi \alpha_\ell)_{-1-1} + (\sigma_\ell \pi \alpha_\ell)_{1-1}](\pi_{1-1} - \pi_{-1-1})\}^{N_0}}$$

when MRCH = 4

(3.67)

where  $(\overline{\quad})^{N_0}$  indicates the smoothing procedure in subroutine AVRX(K) and  $\phi_\ell$  is the geopotential at the levels  $\ell = 1$  and 3 defined by Eqs. (2.16) and (2.17). The geopotential is evaluated at  $\pi$  points in subroutine COMP 2 (steps 5260 to 5430).

For the v-momentum equations [Eqs. (2.28) and (2.30)] the pressure-gradient force is given by

$$\begin{aligned}
 & m_0 \left( \pi \frac{\partial \phi_\ell}{\partial y} + \sigma_\ell \pi \alpha_\ell \frac{\partial \pi}{\partial y} \right)_{\ell,00} \\
 &= m_0 \left\{ \frac{1}{2} \left[ \frac{\pi_{-11} + \pi_{-1-1}}{2} (\phi_{\ell,-11} - \phi_{\ell,-1-1}) + \frac{\pi_{11} + \pi_{1-1}}{2} (\phi_{\ell,11} - \phi_{\ell,1-1}) \right] \right. \\
 &\quad + \frac{1}{2} \left[ \frac{(\sigma_\ell \pi \alpha_\ell)_{-11} + (\sigma_\ell \pi \alpha_\ell)_{-1-1}}{2} (\pi_{-11} - \pi_{-1-1}) \right. \\
 &\quad \left. \left. + \frac{(\sigma_\ell \pi \alpha_\ell)_{11} + (\sigma_\ell \pi \alpha_\ell)_{1-1}}{2} (\pi_{11} - \pi_{1-1}) \right] \right\} \\
 &\quad \text{when MRCH} = 1 \text{ or } 2 \\
 &= m_0 \left[ \frac{\pi_{11} + \pi_{1-1}}{2} (\phi_{\ell,11} - \phi_{\ell,1-1}) + \frac{(\sigma_\ell \pi \alpha_\ell)_{11} + (\sigma_\ell \pi \alpha_\ell)_{1-1}}{2} (\pi_{11} - \pi_{1-1}) \right] \\
 &\quad \text{when MRCH} = 3 \\
 &= m_0 \left[ \frac{\pi_{-11} + \pi_{-1-1}}{2} (\phi_{\ell,-11} - \phi_{\ell,-1-1}) + \frac{(\sigma_\ell \pi \alpha_\ell)_{-11} + (\sigma_\ell \pi \alpha_\ell)_{-1-1}}{2} (\pi_{-11} - \pi_{-1-1}) \right] \\
 &\quad \text{when MRCH} = 4
 \end{aligned}
 \tag{3.68}$$

## 7. Horizontal Advection of Temperature

The horizontal advection of temperature at the level  $\ell$  and for an arbitrary  $\pi$  point at the latitudes from  $\varphi_3$  to  $\varphi_{J-2}$  is given in  $\pi$ -centered notation as

$$\begin{aligned}
 \left[ \frac{\partial}{\partial x} (u^* T) + \frac{\partial}{\partial y} (v^* T) \right]_{\ell,00} &= (u^* T)_{\ell,10} - (u^* T)_{\ell,-10} \\
 &\quad + (v^* T)_{\ell,01} - (v^* T)_{\ell,0-1}
 \end{aligned}
 \tag{3.69}$$

where

$$(u^*T)_{\ell, \pm 10} = u_{\ell, \pm 10}^* \frac{1}{2} (T_{\ell, 00} + T_{\ell, \pm 20}) \quad (3.70)$$

and

$$(v^*T)_{\ell, 0 \pm 1} = v_{\ell, 0 \pm 1}^* \frac{1}{2} (T_{\ell, 00} + T_{\ell, 0 \pm 2}) \quad (3.71)$$

At the poles only the south/north mass flux contributes to the advection of temperature. Thus, for the South Pole, Eq. (3.69) reduces to

$$\left[ \frac{\partial}{\partial x} (u^*T) + \frac{\partial}{\partial y} (v^*T) \right]_{\ell, 0, 1} = (v^*T)_{\ell, 0, p+1} \quad (3.72)$$

where

$$(v^*T)_{\ell, 0, p+1} = v_{\ell, 0, p+1}^* \begin{cases} T_{\ell, 0, 1} \\ T_{\ell, 0, p+2} \end{cases} \text{ if } v_{\ell, 0, p+1}^* \begin{cases} \geq 0 \\ < 0 \end{cases} \quad (3.73)$$

while at the North Pole it reduces to

$$\left[ \frac{\partial}{\partial x} (u^*T) + \frac{\partial}{\partial y} (v^*T) \right]_{\ell, 0, J} = (v^*T)_{\ell, 0, p-1} \quad (3.74)$$

where

$$(v^*T)_{\ell, 0, p-1} = v_{\ell, 0, p-1}^* \begin{cases} T_{\ell, 0, J} \\ T_{\ell, 0, p-2} \end{cases} \text{ if } v_{\ell, 0, p-1}^* \begin{cases} \leq 0 \\ > 0 \end{cases} \quad (3.75)$$

At the latitudes  $\varphi_2$  and  $\varphi_{j-1}$  [the points  $(1, p \pm 2)$  in  $\pi$ -centered notation] the west/east advection term  $(\frac{\partial}{\partial x} u^* T)$  is given a special treatment. The form of the total advection term, analogous to Eq. (3.69), is given at these latitudes by

$$\left[ \frac{\partial}{\partial x} (u^* T) + \frac{\partial}{\partial y} (v^* T) \right]_{\ell, 0, p \pm 2} = (u^* T)_{\ell, 1, p \pm 2} - (u^* T)_{\ell, -1, p \pm 2} \pm (v^* T)_{\ell, 0, p \pm 3} \mp (v^* T)_{\ell, 0, p \pm 1} \quad (3.76)$$

with  $(v^* T)_{\ell, 0, p \pm 1}$  given by Eqs. (3.73) and (3.75), and with

$$(v^* T)_{\ell, 0, p \pm 3} = v_{\ell, 0, p \pm 3}^* \frac{1}{2} (T_{\ell, 0, p \pm 2} + T_{\ell, 0, p \pm 4}) \quad (3.77)$$

$$(u^* T)_{\ell, 1, p \pm 2} = u_{\ell, 1, p \pm 2}^* \begin{cases} T_{\ell, 2, p \pm 2} \\ T_{\ell, 0, p \pm 2} \end{cases} \quad \text{if} \quad u_{\ell, 1, p \pm 2}^* \begin{cases} < 0 \\ \geq 0 \end{cases} \quad (3.78)$$

$$(u^* T)_{\ell, -1, p \pm 2} = u_{\ell, -1, p \pm 2}^* \begin{cases} T_{\ell, -2, p \pm 2} \\ T_{\ell, 0, p \pm 2} \end{cases} \quad \text{if} \quad u_{\ell, -1, p \pm 2}^* \begin{cases} \geq 0 \\ < 0 \end{cases} \quad (3.79)$$

## 8. Energy-Conversion Terms

The first two energy-conversion terms in the thermodynamic energy equations (see Table 3.3) do not require horizontal finite-difference expressions. They are evaluated at  $n$  points in subroutine COM2 1 (steps 4560 to 4660) from the equations

$$\left[ \left( \frac{p_{\ell}}{p_0} \right)^{\kappa} \frac{\theta_1 + \theta_3}{2} \dot{s} \right]_{\ell, 00} = p_{\ell, 00}^{\kappa} \frac{1}{2} \left( \frac{T_{1, 00}}{p_{1, 00}^{\kappa}} + \frac{T_{3, 00}}{p_{3, 00}^{\kappa}} \right) \dot{s}_{00} \quad (3.80)$$

$$\left( \frac{\sigma \alpha \pi}{c_p} \frac{\partial \pi}{\partial t} \right)_{l,00} = \sigma_l \pi_{00} \frac{\kappa T_{l,00}}{p_{l,00}} \left( \frac{\partial \pi}{\partial t} \right)_{00} \quad (3.81)$$

where  $\dot{S}$  and  $\partial \pi / \partial t$  are evaluated at  $\pi$  points using Eqs. (3.36) to (3.41), and the pressure at level  $l$  is given by

$$p_l = p_T + \sigma_l \pi \quad (3.82)$$

In Eq. (3.80) the definition

$$\theta_l = T_l \left( \frac{p_0}{p_l} \right)^\kappa$$

has been used to eliminate the potential temperature, and in Eq. (3.81) the equation of state in the form

$$\alpha_l = c_p \kappa \frac{T_l}{p_l}$$

has been used to eliminate the specific volume.

The remaining energy-conversion terms at the level  $l$  are evaluated from the expression

$$\begin{aligned} \left[ \frac{\sigma \alpha}{c_p} \left( u^* \frac{\partial \pi}{\partial x} + v^* \frac{\partial \pi}{\partial y} \right) \right]_{l,00} = \frac{1}{c_p} \frac{1}{2} \left[ (\sigma \alpha u^* \frac{\partial \pi}{\partial x})_{l,-10} \right. \\ \left. + (\sigma \alpha u^* \frac{\partial \pi}{\partial x})_{l,10} + (\sigma \alpha v^* \frac{\partial \pi}{\partial y})_{l,0-1} + (\sigma \alpha v^* \frac{\partial \pi}{\partial y})_{l,01} \right] \quad (3.83) \end{aligned}$$

where  $\pi$ -centered notation has been used, and where

$$\left(\sigma_{\alpha u}^* \frac{\partial}{\partial x}\right)_{\ell, \pm 10} = (\pm \pi_{\pm 20} \mp \pi_{00}) [(\sigma_{\alpha \pi})_{\ell, \pm 20} + (\sigma_{\alpha \pi})_{\ell, 00}] / 2$$

$$\times \begin{cases} \frac{n_{1u, \pm 11} + n_{-1u, \pm 1-1}}{2}^{N_0} & \text{if MRCH} = 1 \text{ or } 2 \\ (n_{1u, 11})^{N_0} & \text{if MRCH} = 3 \\ (n_{-1u, \pm 1-1})^{N_0} & \text{if MRCH} = 4 \end{cases} \quad (3.84)$$

$$\left(\sigma_{\alpha v}^* \frac{\partial \pi}{\partial y}\right)_{\ell, 0 \pm 1} = (\pm \pi_{0 \pm 2} \mp \pi_{00}) [(\sigma_{\alpha \rho})_{\ell, 0 \pm 2} + (\sigma_{\alpha \rho})_{\ell, 00}] / 2$$

$$\times \begin{cases} \frac{m_{\pm 1v, 1 \pm 1} + m_{\pm 1v, -1 \pm 1}}{2} & \text{if MRCH} = 1 \text{ or } 2 \\ m_{\pm 1v, 1 \pm 1} & \text{if MRCH} = 3 \\ m_{-1v, -1 \pm 1} & \text{if MRCH} = 4 \end{cases} \quad (3.85)$$

In Eq. (3.84),  $(\quad)^{N_0}$  denotes the zonal smoothing routine in subroutine AVRX(K) (see Chapter III, Subsection C.1).

## 9. Horizontal Advection of Moisture

As discussed in Chapter II, moisture is carried only at the level  $\ell = 3$ . Furthermore, the moisture is considered to be advected by the average wind in the layer between  $\ell = 3$  and the surface. By linear extrapolation to the surface of the winds at levels  $\ell = 1$  and  $\ell = 3$ , the average pressure-area-weighted wind in this layer is given by the equations

$$\begin{aligned}\frac{u_3^* + u_4^*}{2} &= \frac{5}{4} u_3^* - \frac{1}{4} u_1^* \\ \frac{v_3^* + v_4^*}{2} &= \frac{5}{4} v_3^* - \frac{1}{4} v_1^*\end{aligned}\tag{3.86}$$

Using Eqs. (3.86) for the advecting wind, the expressions for the west/east and south/north moisture advection at  $\pi$  points outside the poles are given in  $\pi$ -centered notation by

$$\begin{aligned}\left\{ \frac{\partial}{\partial x} \left[ q_3 \left( \frac{5}{4} u_3^* - \frac{1}{4} u_1^* \right) \right] \right\}_{3,00} &= \frac{5}{4} \left[ \left( q_3 u_3^* \right)_{3,10} - \left( q_3 u_3^* \right)_{3,-10} \right] \\ &\quad - \frac{1}{4} \left[ \left( q_3 u_1^* \right)_{3,10} - \left( q_3 u_1^* \right)_{3,-10} \right]\end{aligned}\tag{3.87}$$

and

$$\begin{aligned}\left\{ \frac{\partial}{\partial y} \left[ q_3 \left( \frac{5}{4} v_3^* - \frac{1}{4} v_1^* \right) \right] \right\}_{3,00} &= \frac{5}{4} \left[ \left( q_3 v_3^* \right)_{3,01} - \left( q_3 v_3^* \right)_{3,0-1} \right] \\ &\quad - \frac{1}{4} \left[ \left( q_3 v_1^* \right)_{3,01} - \left( q_3 v_1^* \right)_{3,0-1} \right]\end{aligned}\tag{3.88}$$

Physically the moisture parameter  $q$  is a non-negative quantity. Therefore, the fluxes  $\left( q_3 u_3^* \right)_{3,01}$ , etc. on the right-hand sides of Eqs. (3.87) and (3.88) must be defined in such a way that when a grid cell becomes "dry," advection to neighboring cells will be prevented. With this restriction, the moisture fluxes in  $\pi$ -centered notation are given by



$$\begin{pmatrix} (q_3 u_3^*)_{3,10} \\ (q_3 u_1^*)_{3,10} \end{pmatrix} = \begin{pmatrix} u_{3,10}^* \\ u_{1,10}^* \end{pmatrix} \times \begin{cases} 0 & \text{if } (q_{3,00} + q_{3,20}) < 10^{-10} \\ 2 \frac{q_{3,00} q_{3,20}}{q_{3,00} + q_{3,20}} & \text{if } \begin{cases} q_{3,00} < q_{3,20} \text{ and } \begin{pmatrix} u_{3,10}^* > 0 \\ u_{1,10}^* < 0 \end{pmatrix} \\ \text{or} \\ q_{3,00} > q_{3,20} \text{ and } \begin{pmatrix} u_{3,10}^* < 0 \\ u_{1,10}^* > 0 \end{pmatrix} \end{cases} \\ \frac{q_{3,00} + q_{3,20}}{2} & \text{otherwise} \end{cases} \quad (3.89)$$

$$\begin{pmatrix} (q_3 u_3^*)_{3,-10} \\ (q_3 u_1^*)_{3,-10} \end{pmatrix} = \begin{pmatrix} u_{3,-10}^* \\ u_{1,-10}^* \end{pmatrix} \times \begin{cases} 0 & \text{if } (q_{3,00} + q_{3,0-2}) < 10^{-10} \\ 2 \frac{q_{3,00} q_{3,-20}}{q_{3,00} + q_{3,-20}} & \text{if } \begin{cases} q_{3,-20} < q_{3,00} \text{ and } \begin{pmatrix} u_{3,-10}^* > 0 \\ u_{1,-10}^* < 0 \end{pmatrix} \\ \text{or} \\ q_{3,-20} > q_{3,00} \text{ and } \begin{pmatrix} u_{3,-10}^* < 0 \\ u_{1,-10}^* > 0 \end{pmatrix} \end{cases} \\ \frac{q_{3,00} + q_{3,-20}}{2} & \text{otherwise} \end{cases} \quad (3.90)$$

$$\begin{pmatrix} (q_3 v_3^*)_{3,01} \\ (q_3 v_1^*)_{3,01} \end{pmatrix} = \begin{pmatrix} v_{3,01}^* \\ v_{1,01}^* \end{pmatrix} \times \begin{cases} 0 & \text{if } (q_{3,00} + q_{3,02}) < 10^{-10} \\ 2 \frac{q_{3,00} q_{3,02}}{q_{3,00} + q_{3,02}} & \text{if } \begin{cases} q_{3,00} < q_{3,02} \text{ and } \begin{pmatrix} v_{3,01}^* > 0 \\ v_{1,01}^* < 0 \end{pmatrix} \\ \text{or} \\ q_{3,00} > q_{3,02} \text{ and } \begin{pmatrix} v_{3,01}^* < 0 \\ v_{1,01}^* > 0 \end{pmatrix} \end{cases} \\ \frac{q_{3,00} + q_{3,02}}{2} & \text{otherwise} \end{cases} \quad (3.91)$$

$$\begin{pmatrix} (q_3 v_3^*)_{3,0-1} \\ (q_3 v_1^*)_{3,0-1} \end{pmatrix} = \begin{pmatrix} v_{3,0-1}^* \\ v_{1,0-1}^* \end{pmatrix} \times \begin{cases} 0 & \text{if } (q_{3,00} + q_{3,0-2}) < 10^{-10} \\ 2 \frac{q_{3,00} q_{3,0-2}}{q_{3,00} + q_{3,0-2}} & \text{if } \begin{cases} q_{3,0-2} < q_{3,00} \text{ and } \begin{pmatrix} v_{3,0-1}^* > 0 \\ v_{1,0-1}^* < 0 \end{pmatrix} \\ \text{or} \\ q_{3,0-2} > q_{3,00} \text{ and } \begin{pmatrix} v_{3,0-1}^* < 0 \\ v_{1,0-1}^* > 0 \end{pmatrix} \end{cases} \\ \frac{q_{3,00} + q_{3,0-2}}{2} & \text{otherwise} \end{cases} \quad (3.92)$$

In the polar caps only the south/north advection terms given by Eq. (3.88) contribute to the advection of moisture. In  $\pi$ -centered polar notation, Eq. (3.88) at the South Pole becomes

$$\left\{ \frac{\partial}{\partial y} \left[ q_3 \left( \frac{5}{4} v_3^* - \frac{1}{4} v_1^* \right) \right] \right\}_{3,01} = \frac{5}{4} (q_3 v_3^*)_{3,0,p+1} - \frac{1}{4} (q_3 v_3^*)_{3,0,p+1} \quad (3.93)$$

and at the North Pole

$$\left\{ \frac{\partial}{\partial y} \left[ q_3 \left( \frac{5}{4} v_3^* - \frac{1}{4} v_1^* \right) \right] \right\}_{3,0J} = -\frac{5}{4} (q_3 v_3^*)_{3,0,p-1} + \frac{1}{4} (q_3 v_1^*)_{3,0,p-1} \quad (3.94)$$

where the fluxes on the right-hand side of Eq. (3.93) are given by Eq. (3.91) and those on the right-hand side of Eq. (3.94) are given by Eq. (3.92).

#### 10. Horizontally Differenced Friction Terms

The friction terms  $F_1^{x,y}$  and  $F_3^{x,y}$  appearing in the equations of motion (2.27) to (2.30) are given in horizontally differenced form in  $u, v$  notation by

$$F_{1,00}^x = -g\beta(u_{1,00} - u_{3,00})(\pi_{00}^u)^{-2} \quad (3.95)$$

$$F_{1,00}^y = -g\beta(v_{1,00} - v_{3,00})(\pi_{00}^u)^{-2} \quad (3.96)$$

$$F_{3,00}^x = g\beta(u_{1,00} - u_{3,00})(\pi_{00}^u)^{-2} - \frac{2g}{\pi_{00}^u} c_D \frac{\pi_{00}^u + p_T}{RT_{4,00}^u} \left( |\vec{v}_s|_{00}^\pi + G \right) (0.7)u_{4,00} \quad (3.97)$$

$$F_{3,00}^y = g\beta(v_{1,00} - v_{3,00})(\pi_{00}^u)^{-2} - \frac{2g}{\pi_{00}^u} C_D \frac{(\pi_{00}^u + p_T)}{RT_{4,00}^u} \left( |\vec{v}_s|_{00}^\pi + G \right) (0.7)v_{4,00} \quad (3.98)$$

These forms rest upon the approximation of the height difference  $(z_1 - z_3)$  in Eq. (2.36) by  $\Delta z(\pi/\pi_S)$ , where  $\Delta z (= 5400 \text{ m})$  and  $\pi_S (= 900 \text{ mb})$  are standard values of  $(z_1 - z_3)$  and  $\pi$ , respectively. The coefficient  $\beta$  thus becomes  $\beta = 2\pi_S \mu (\Delta z)^{-1}$ , and is taken as  $0.13 \text{ mb}^2 \text{ sec m}^{-1}$ , corresponding to  $\mu = 0.44 \text{ mb sec}$ .

In Eqs. (3.97) and (3.98) the surface wind speed  $|\vec{v}_s|_{00}^\pi$  is given (in u,v notation) by

$$|\vec{v}_s|_{00}^\pi = \frac{1}{2} \left( |\vec{v}_s|_{00}^2 + |\vec{v}_s|_{-20}^2 + |\vec{v}_s|_{02}^2 + |\vec{v}_s|_{-22}^2 \right)^{1/2} \quad (3.99)$$

where  $\vec{v}_s = 0.7|\vec{v}_4|$  and where  $\vec{v}_4 = \frac{3}{2}\vec{v}_3 - \frac{1}{2}\vec{v}_1 = (u_4, v_4)$  is the wind extrapolated to level 4. Here the subscripts refer to the u,v grid (see Fig. 3.7). The gustiness term is given by the constant  $G = 2.0 \text{ m sec}^{-1}$ . The surface drag coefficient is given by the relations

$$C_D = \begin{cases} \min \left[ \left( 1.0 + 0.07 |\vec{v}_s|_{00}^\pi \right) 10^{-3}, 0.0025 \right], & \text{if ocean} \\ 0.002 + 0.006(z_4/5000 \text{ m}), & \text{otherwise} \end{cases} \quad (3.100)$$

where  $z_4$  is the elevation of the surface of the ground. Hence  $C_D$  varies between 0.001 and 0.0025 over the ocean, while over either bare land or ice,  $C_D$  is independent of the wind speed and varies between 0.002 over lowlands and sea ice to about 0.007 over the higher mountains. This increase of the drag coefficient with  $z_4$  is an attempt to simulate the increased roughness or ruggedness of the terrain in higher elevations, as suggested by the work of Cressman (1960).

As elsewhere in this section, the subscript 00 (in u,v-centered notation) denotes an arbitrary point of the u,v grid, and the superscript u denotes the average of the four surrounding points of the  $\pi$  (or primary) grid. Hence

$$\pi_{00}^u = \frac{1}{4} (\pi_{-11} + \pi_{11} + \pi_{-1-1} + \pi_{1-1}) \quad (3.101)$$

recalling that the  $\pi$  grid is displaced upward and to the left of the u,v grid (see Fig. 3.2). The factor  $(\pi_{00}^u + p_T)(RT_{4,00}^u)^{-1}$  in Eqs. (3.97) and (3.98) is thus the surface air density  $\rho_4$ . This averaging serves to "center" the pressure and temperature on the local velocity point. Note, however, that  $|\vec{V}_s|_{00}^\pi$  also involves a 4-point averaging; although this is unnecessary for a point of the u,v grid, it is consistent with the calculation of the surface evaporation and sensible heat flux at points of the  $\pi$  grid (where averaging over velocity points is necessary).

In the program the frictional terms (3.95) to (3.98) are computed every fifth time step as part of the COMP 3 subroutine (instructions 9700 to 9920), and directly give the frictionally induced speed change in  $m \sec^{-1}$  for the  $5\Delta t = 30$  min interval. The factor  $\Pi$  in Eqs. (2.27) to (2.30) is effectively divided out in the finite-difference computations.

### 11. Moisture-Source Terms

The source term  $2mng(E - C)$  in the moisture equation (2.35) may be written in differenced form as

$$\begin{aligned} 2mng(E - C) &= 2(mn)_{00}g(E - C)_{00} \\ &= \frac{\pi_{00}}{5\Delta t} \left[ (\Delta q_3)_E - (\Delta q_3)_{LS} - (\Delta q_3)_{CM} - (\Delta q_3)_{CP} \right]_{00} \end{aligned} \quad (3.102)$$

where the subscript 00 denotes (in  $\pi$ -centered notation) an arbitrary point of the  $\pi$  grid (see Fig. 3.6). This source computation is carried out for level 3 every five time steps in subroutine COMP 3, instructions

11300 to 11310. Here the level-3 moisture change (in  $5\Delta t$ ) due to evaporation is given by

$$(\Delta q_3)_{E,00} = \frac{2g}{\pi_{00}} E_{00} 5\Delta t \quad (3.103)$$

according to Eq. (2.111), where  $E_{00}$  is the local evaporation rate itself. The level-3 moisture change due to large-scale condensation is given by

$$(\Delta q_3)_{LS,00} = \frac{c_p}{L} (\Delta T_3)_{LS,00} \quad (3.104)$$

where  $(\Delta T_3)_{LS}$  is the local temperature change (over  $5\Delta t$ ) at level 3 due to the large-scale latent-heat release, as given by Eq. (2.47). The level-3 moisture change due to middle-level convection is given by

$$(\Delta q_3)_{CM,00} = \frac{c_p}{L} \left[ (\Delta T_1)_{CM,00} + (\Delta T_3)_{CM,00} \right] \quad (3.105)$$

where  $(\Delta T_1)_{CM,00}$  and  $(\Delta T_3)_{CM,00}$  are the temperature changes (over  $5\Delta t$ ) at levels 1 and 3 due to the latent-heat release in middle-level convective condensation, as given by Eqs. (2.73) and (2.74), respectively. Finally, the moisture change at level 3 due to penetrating convection is given by

$$(\Delta q_3)_{CP,00} = \frac{c_p}{L} \left[ (\Delta T_1)_{CP,00} + (\Delta T_3)_{CP,00} \right] \quad (3.106)$$

where  $(\Delta T_1)_{CP,00}$  and  $(\Delta T_3)_{CP,00}$  are the temperature changes (over  $5\Delta t$ ) at levels 1 and 3 due to the release of latent heat in penetrating convective condensation, as given by Eqs. (2.101) and (2.102), respectively.

The three moisture-change terms, Eqs. (3.104) to (3.106), collectively constitute the total moisture sink due to condensation, which we may then write as

$$\left[ (\Delta q_3)_{LS} + (\Delta q_3)_{CM} + (\Delta q_3)_{CP} \right]_{00} = \frac{2g}{\pi_{00}} C_{00} 5\Delta t \quad (3.107)$$

in analogy with (3.103) for the evaporation. Since all condensed water vapor is assumed to fall out as precipitation, we may also rewrite Eq. (3.107) in the form

$$C_{00} = (P_{LS} + P_{CM} + P_{CP})_{00} \quad (3.108)$$

where  $P_{LS}$ ,  $P_{CM}$ , and  $P_{CP}$  are the precipitation rates resulting from large-scale condensation, middle-level convection, and penetrating convection, as given by Eqs. (2.50), (2.76), and (2.107), respectively.

## 12. Diabatic Heating Terms

The heating terms  $\pi \dot{H}_1 / c_p$  and  $\pi \dot{H}_3 / c_p$  in Eqs. (2.31) and (2.32) may be written in differenced form as

$$\pi_{00} \dot{H}_{1,00} / c_p \quad (3.109)$$

$$\pi_{00} \dot{H}_{3,00} / c_p \quad (3.110)$$

where the subscript 00 (in  $\pi$ -centered notation) denotes an arbitrary point of the  $\pi$  grid. These terms are computed every fifth time step in the subroutine COMP 3. Here the diabatic heating rates at levels 1 and 3 are given by

$$(c_p)^{-1} \dot{H}_{1,00} = (A_1 + R_2 - R_0)_{00} \left( \frac{2g}{\pi_{00} c_p} \right) + \left[ (\Delta T_1)_{CM} + (\Delta T_1)_{CP} \right]_{00} / 5\Delta t \quad (3.111)$$

$$(c_p)^{-1} \dot{H}_{3,00} = (A_3 + R_4 - R_2)_{00} \left( \frac{2g}{\pi_{00} c_p} \right) + \Gamma_{00} \left( \frac{2g}{\pi_{00} c_p} \right) + \left[ (\Delta T_3)_{CM} + (\Delta T_3)_{CP} + (\Delta T_3)_{LS} \right]_{00} / 5\Delta t \quad (3.112)$$

according to Eqs. (2.173) and (2.174), where  $A_1$  and  $A_3$  are the net short-wave radiation absorbed at levels 1 and 3, and  $R_2 - R_0$  and  $R_4 - R_2$  are the net long-wave radiation absorbed at the two levels. These terms in Eqs. (3.111) and (3.112) therefore constitute the radiative portions of the diabatic heating. The lower-level heating also contains a contribution from the vertical sensible heat flux from the surface  $\Gamma_{00}$ . The terms in  $(\Delta T_1)$  and  $(\Delta T_3)$  are the temperature changes due to convective effects, with the subscript CM denoting midlevel convection and CP denoting penetrating or deep convection. Together with the term in the level-3 temperature change due to large-scale condensation, LS, these terms constitute the portions of the diabatic heating due to the release of the latent heat of condensation, as considered in Eqs. (3.104) to (3.106). The total diabatic heating is illustrated in Map 8, Chapter IV.

#### D. SMOOTHING

Aside from the smoothing built into the time finite-difference approximations themselves, relatively little explicit smoothing is performed in the present version of the program. The subroutine AVRX(K), which performs a three-point zonal averaging, is employed in the main subroutines COMP 1 and COMP 2 principally for the mass-flux variables  $u_1^*$  and  $u_3^*$ , as described in Subsection C.1 above. The only other use of AVRX(K) is with the zonal-pressure force terms  $\left( \pi \frac{\partial \phi_1}{\partial x} + \sigma_1 \pi \alpha_1 \frac{\partial \pi}{\partial x} \right)$  and  $\left( \pi \frac{\partial \phi_3}{\partial x} + \sigma_3 \pi \alpha_3 \frac{\partial \pi}{\partial x} \right)$  in the momentum equations, as described in

Subsection C.6 above. The effect of the use of subroutine AVRX(K) is to introduce a multiple-point zonal difference for higher latitudes to help avoid computational instability; the variables such as  $u_1^*$  are not themselves smoothed.

This selective zonal averaging subroutine is called every time step, with the number of smoothing passes made at each step (as well as the smoothing weighting factor) increasing with latitude. Denoting  $(\bar{\phantom{x}})$  the smoothed value of a variable  $(\phantom{x})$ , the zonal smoothing subroutine AVRX(K) may be described by

$$(\bar{\phantom{x}})_{00} = \lambda_0(\phantom{x})_{-10} + (1 - 2\lambda_0)(\phantom{x})_{00} + \lambda_0(\phantom{x})_{10}$$

where the subscripts denote identity points in the  $(i,j)$  grid array, and where the weighting or smoothing factor  $\lambda_0$  is given by

$$\lambda_0 = \begin{cases} 0, & \text{for } N_0 < 1 \\ [1/8(n_e/m_0 - 1)]/N_0, & \text{for } N_0 \geq 1 \end{cases}$$

Here  $n_e$  is the latitudinal separation of grid points at the equator,  $m_0$  is the longitudinal separation of  $\pi$  points at the latitude of the smoothing, and  $N_0$  is the integer part of  $(n_e/m_0)$ . The smoothing is applied  $N_0$  times at each latitude, as shown in Table 5.7. Note that the number of applications of the smoothing operator increases from zero between the equator and  $\pm 34$  deg latitude to 11 near the poles. The strength of the smoothing as given by  $\lambda_0$  is also seen to vary with latitude.

An explicit smoothing occurs in the subroutine COMP 3, where the heating rates  $\dot{H}_1$  and  $\dot{H}_3$  for the two model layers [as in Eqs. (2.31) and (2.32)] are first averaged together, area weighted, and then subjected to a 9-point horizontal averaging prior to their final incorporation into the temperature-change computation at each level. This smoothing is described as part of the subroutine COMP 3 (see Chapter II, Subsection G.4).



Table 3.7

SMOOTHING PARAMETERS USED IN SUBROUTINE AVRX(K)

Here  $\lambda_0$  is the three-point smoothing weighting factor [as in Eq. (3.27)] and  $N_0$  is the number of times the smoothing is repeated at each latitude.

$\varphi$ , deg (LAT)	$N_0$ (NM)	$\lambda_0$ (ALPHA)
-34 to +34	0	0
±38	1	$1.90 \times 10^{-3}$
±42	1	$9.56 \times 10^{-3}$
±46	1	$1.90 \times 10^{-2}$
±50	1	$3.06 \times 10^{-2}$
±54	1	$4.51 \times 10^{-2}$
±58	1	$6.37 \times 10^{-2}$
±62	1	$8.80 \times 10^{-2}$
±66	1	$1.21 \times 10^{-1}$
±70	2	$8.37 \times 10^{-2}$
±74	2	$1.19 \times 10^{-1}$
±78	3	$1.19 \times 10^{-1}$
±82	5	$1.19 \times 10^{-1}$
±86	11	$1.19 \times 10^{-1}$

The remaining smoothing operations are performed on the lapse rate in the subroutine COMP 4, which is called every 5 time steps. Here the temperature at levels 1 and 3 is smoothed according to

$$T_1 = \frac{1}{2} (T_3 + T_1) - \pi [TD + \frac{1}{48} (\overline{TD} - TD)] \quad (3.113)$$

$$T_3 = \frac{1}{2} (T_3 + T_1) + \pi [TD + \frac{1}{48} (\overline{TD} - TD)] \quad (3.114)$$

where the temperature difference (or lapse rate) TD is given by

$$TD = \frac{1}{\pi} \left( \frac{T_3 - T_1}{2} \right) \quad (3.115)$$

and  $(\overline{\phantom{x}})$  denotes the 9-point horizontal average about a point 00 of the  $\pi$  grid, given in  $\pi$ -centered notation by

$$\begin{aligned} \overline{TD}_{00} = \frac{1}{16} (TD_{-22} + 2TD_{02} + TD_{22} + 2TD_{-20} + 4TD_{00} \\ + 2TD_{20} + TD_{-2-2} + 2TD_{0-2} + TD_{2-2}) \end{aligned} \quad (3.116)$$

Since the first terms of Eqs. (3.113) and (3.114) are a form of vertical averaging, this subroutine may be regarded as a three-dimensional smoothing operation, wherein the temperature at levels 1 and 3 is altered in proportion to the departure of the local lapse rate from the 9-point averaged lapse rate. If  $TD = \overline{TD}$ , for example,  $T_1$  and  $T_3$  remain unaltered by this smoothing. Viewed in another fashion, from Eqs. (3.113) and (3.114) we have

$$\frac{T_3 - T_1}{2\pi} = TD_{\text{smoothed}} = TD + \frac{1}{48} (\overline{TD} - TD) \quad (3.117)$$

and the averaging may be regarded as a local smoothing of the lapse rate.

Another part of the subroutine COMP 4 (instructions 12270 to 12680) provides for the smoothing of the local velocity change through the simulation of a horizontal diffusion of momentum. This portion is omitted in the present version of the code through the assignment of a zero lateral-diffusion coefficient.

#### E. GLOBAL MASS CONSERVATION

Although the continuity equation (2.33) is solved at each (mass) point of the grid at each time step (see Chapter III, Subsection C.2), a small loss of mass over the globe still occurs because of the truncation caused by the retention of at most 7 decimal digits in the single-precision calculation (which does not round) of the surface pressure on the IBM 360/91 computer.<sup>+</sup> Over the globe this amounts to approximately a 0.0028 percent ( $2.8 \times 10^{-5}$ ) loss of mass per day of simulated time. To correct for this effect, the subroutine GMP is used once every 24 hours; in GMP the local value of the surface pressure parameter,  $\pi$ , is increased (at every point) by the amount  $984 \text{ mb} - \bar{p}_s$ , where  $\bar{p}_s$  is the global average surface pressure determined each day (as the sum of the global average of the current  $\pi$  distribution and the constant tropopause pressure  $p_T = 200 \text{ mb}$ ). Here the constant 984 mb is used to represent the observed global average surface pressure, and is read into the program as the loaded constant PSF. In the present version of the program this correction at each --grid point thus amounts to approximately 0.028 mb per day.

#### F. CONSTANTS AND PARAMETERS

##### 1. Numerical Data List

Although a number of the constants and parameters used in the model integration are given elsewhere [see particularly the chapters on model performance (IV), the list of symbols (VI), and the FORTRAN dictionary (VIII)], it is useful to collect them here for easy reference.

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<sup>+</sup> Presumably this loss would be reduced by the use of double-precision arithmetic.

Those symbols with an asterisk (\*) are defined within the subroutines COMP 3 or INPUT, with the others loaded via data cards (see Chapter IV, Section A).

<u>Constant</u>	<u>Symbol</u>	<u>Value and Units</u>
ratio of latent heat of condensation to specific heat at constant pressure, $L/c_p$	CLH*	580/0.24 deg
length of day	DAY	86,400 sec
days per year	DAYPYR*	365 days
maximum solar declination	DECMAX*	$23.5\pi/180$ radians
north/south grid-point spacing	DLAT	4 deg
east/west grid-point spacing	DLON*	$2\pi/IM$ radians (= 5 deg)
time step, $\Delta t$	DT*	360 sec
time step, $\Delta t$	DTM	6 min
standard value of vertical eddy mixing coefficient	ED	$10 \text{ m}^2 \text{ sec}^{-1}$
gravity, $g$	GRAV	$9.81 \text{ m sec}^{-2}$
vertical shear-stress coefficient ( $\times 10^{-5}$ )	FMX	$0.2 \text{ sec}^{-1}$
grid points in meridional direction	JM	46
grid points in zonal direction	IM	72
thermodynamic ratio, $\kappa$	KAPA	0.286
frequency of source-term calculation	NC3	5 (every 30 min)
average surface pressure	PSF	984 mb
standard sea-level pressure	PSL	1000 mb
tropopause pressure, $p_T$	PTRØP	200 mb

<u>Constant</u>	<u>Symbol</u>	<u>Value and Units</u>
earth's radius, $a$	RAD	$6.3750 \times 10^6$ m
dry-air gas constant, $R$	RGAS	$287.0 \text{ m}^2 \text{ deg}^{-1} \text{ sec}^{-2}$
solar rotation period	ROTPER*	24 hr
upper model level, $\sigma_1$	SIG(1)*	0.25
lower model level, $\sigma_3$	SIG(2)*	0.75
solar constant (normalized)	SØ*	$2880 \text{ ly day}^{-1}$ ( $= 2 \text{ ly min}^{-1}$ )
freezing temperature	TICE*	273.1 deg K

## 2. Geographical Finite-Difference Grid

The specific geographical position of the points of the 46 by 72 grid is shown in Fig. 3.12. Here the grid points of the primary or  $\pi$  grid are given over the oceans every 4 deg latitude and 5 deg longitude, together with the outlines of the continents and islands resolved by the interlocking points of the  $u,v$  grid. The left-hand and right-hand columns of grid points are at 180 deg longitude; the top and bottom rows are at the North and South Poles, respectively, with the latitude identification on the right of the figure. The finite-difference indices  $i$  and  $j$  are shown on the bottom and left side of the figure, respectively. This map is on the same scale as that used to show the land elevations and sea-surface temperatures in Figs. 3.13 and 3.14, and is the same as that used for the selected variables produced by the map-generation program in the figures of Chapter IV.

## 3. Surface Topography (Elevation, Sea-Surface Temperature, Ice, and Snow Cover)

During the course of a numerical simulation, the land surface elevation and the ocean surface temperature are held fixed, and thus serve as physical surface boundary conditions. Although these data may conceivably be changed from one simulation to another, their normal distributions are shown in Figs. 3.13 and 3.14 in the form of the programmed Map 5 output (see Map Routine Listing, Chapter VII), and

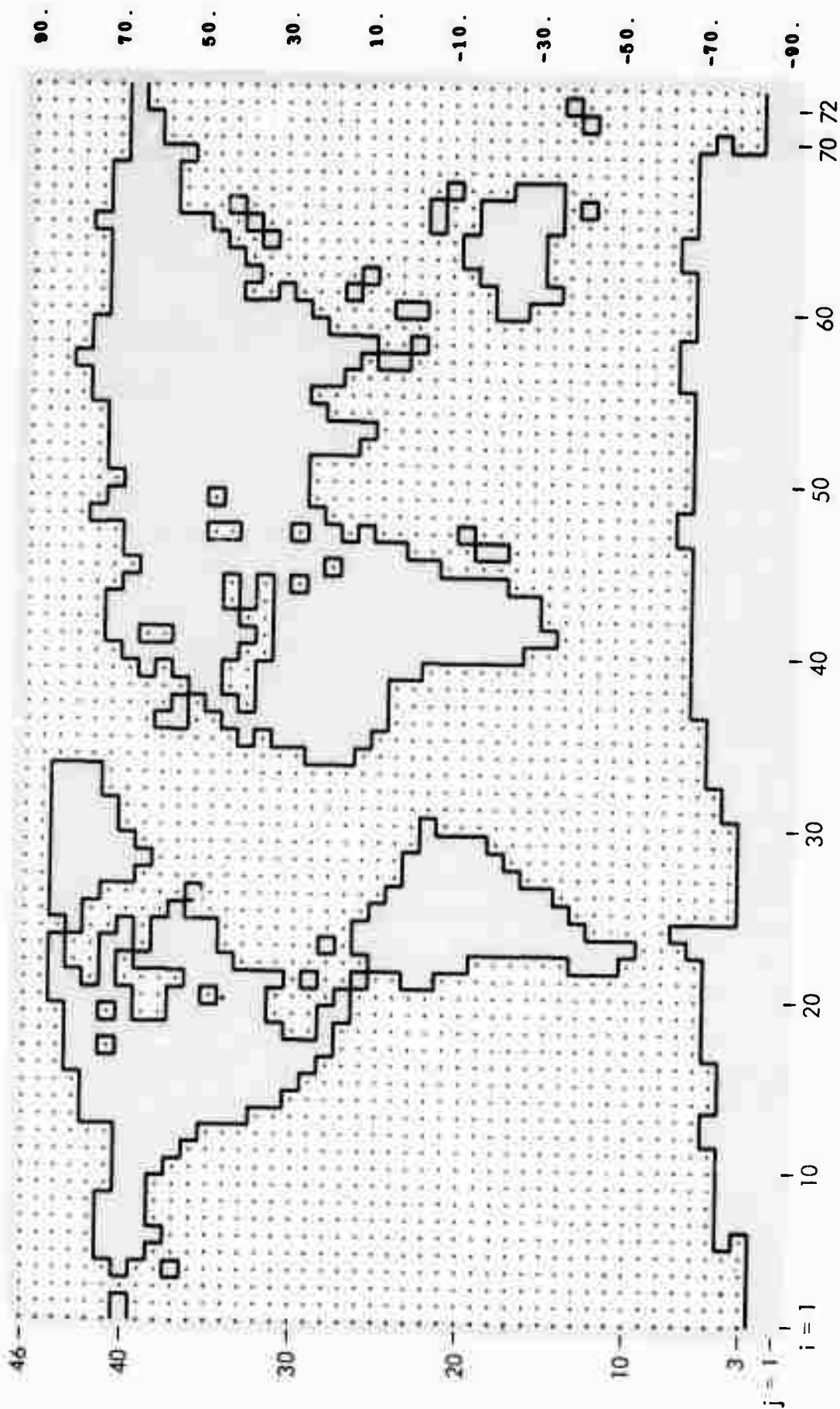


Fig. 3.12 -- The geographical grid and land-mass outlines. The points shown over water surfaces are those of the primary or  $\pi$  grid every  $4^\circ$  latitude and  $5^\circ$  longitude (90S, ..., 6S, 2S, 2N, 6N, ..., 90N; 180W, 175W, ...). The continental and major island outlines are formed by zonal and meridional lines connecting points of the u,v grid (88S, ..., 4S, 0, 4N, ..., 88N; 177.5W, 172.5W, ...). The latitude is shown on the right, and the longitude of both the left-hand and right-hand columns is  $180^\circ$ W. The grid indexes  $i$  and  $j$  (for the  $\pi$  grid) are shown on the bottom and left, respectively. This map is on the same scale as those of Figs. 3.13, 3.14, and 4.1 to 4.31.

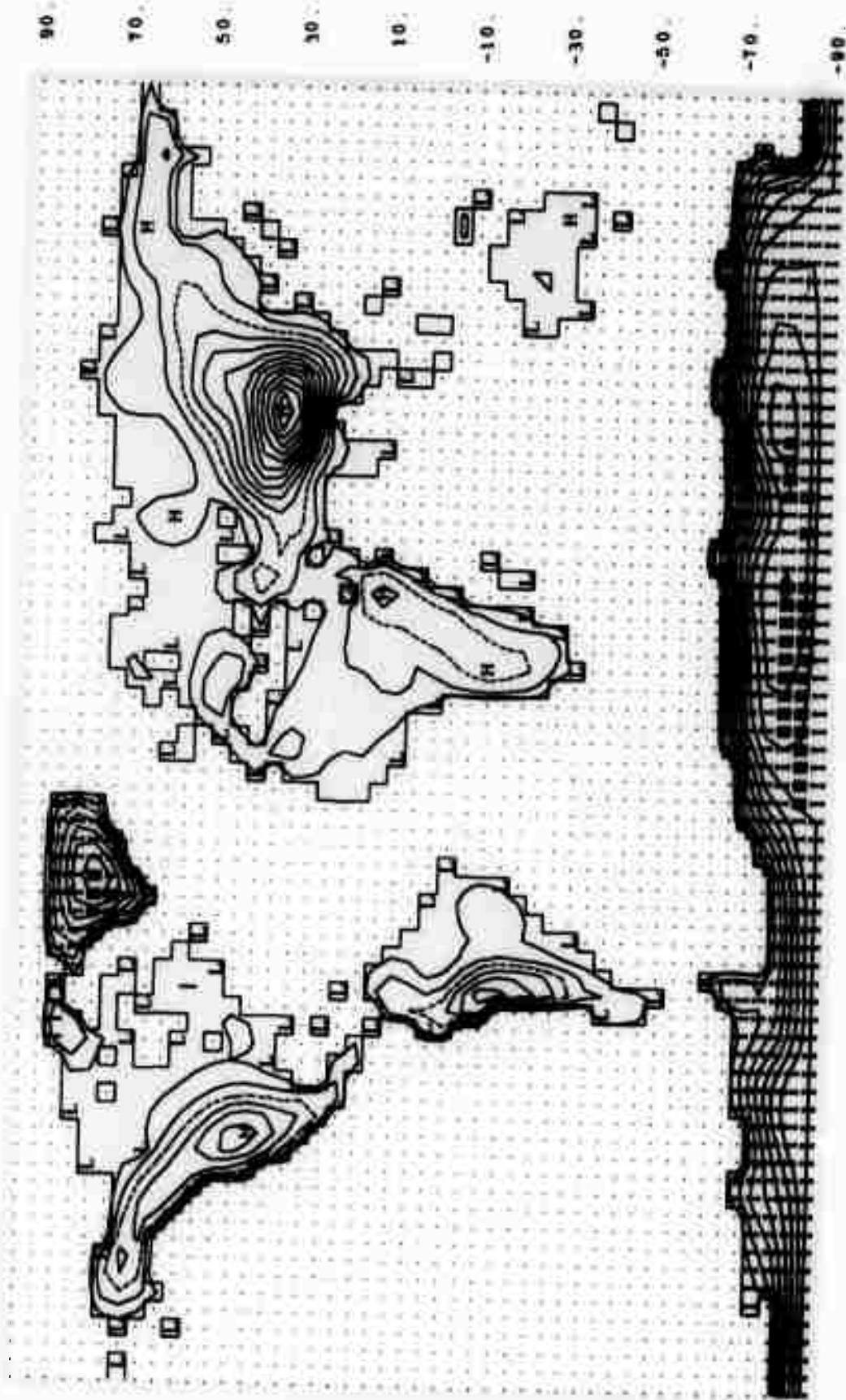


Fig. 3.13 -- The distribution of surface elevation, with isolines every  $10^3$  ft and the 3000-ft contour dashed. The overprinted symbol I denotes ice-covered land. The grid-point elevation data themselves are given in Table 3.8.

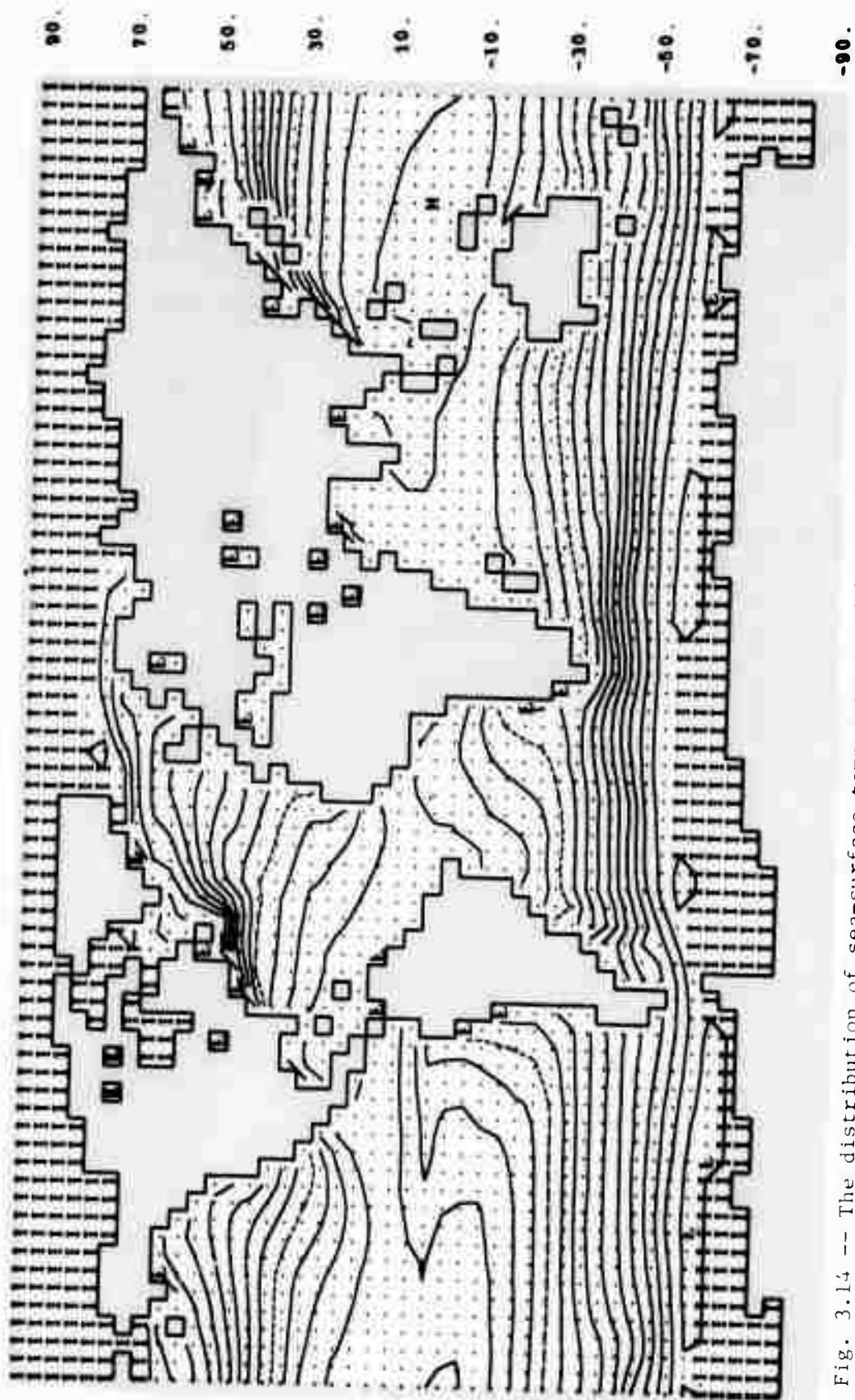


Fig. 3.14 -- The distribution of sea-surface temperature, with isolines every 2 deg C and the 20°C isotherm dashed. The overprinted symbol I denotes ice-covered ocean. The grid-point temperature data themselves are given in Table 3.10.



the corresponding global grid-point values are given every 5 deg longitude and 4 deg latitude (at the points of the  $\pi$  grid) in the tabulation following the maps.

The land elevations shown in Fig. 3.13 are based upon the values at points of the 4 deg latitude, 5 deg longitude grid (see data tabulation), which were themselves obtained from the subjective interpolation of topographic maps. These data resemble (but are not identical to) the data given by Berkofsky and Bertoni (1955), and are tabulated in Table 3.8. In Fig. 3.13 the overprinted symbol I designates those grid points at which the land is ice covered; in the data tabulation, the elevation of these points is given separately in Table 3.9, where 0 denotes the locations of sea ice. In the present version of the model, the ice-covered points are not permitted to change their surface cover during the course of the simulation.

The ocean surface temperatures shown in Fig. 3.14 are based upon the values at points of the 4 deg latitude, 5 deg longitude grid (see data tabulation) which were obtained from the average annual sea-surface temperature data given by Dietrich (1963). These data resemble (but are not identical to) the mean of the average February and August distributions given by Sverdrup (1943), and are tabulated in Table 3.10. In Fig. 3.14 the overprinted symbol I here designates those  $\pi$ -grid points at which sea ice is prescribed (and held intact throughout the simulation); in the data tabulation these sea-ice points may be identified by the assigned constant temperature 0 deg C (see Table 3.9). Because the ocean's surface temperature is not allowed to change, even though there are evaporation, radiative transfer, and sensible-heat fluxes at the surface, the ocean has effectively been assumed to be of infinite thermal capacity. The surface temperatures of the sea ice, land ice, snow-covered land, and bare land, on the other hand, are allowed to change, and are separately computed (see COMP 3 in the Program Listing, Chapter VII).

All land grid points north of a seasonally varying northern snowline (SNOWN) are considered to be snow covered. Snow does not cover either ice-covered land or sea ice. The northern snowline has a 15-deg sinusoidal seasonal variation around 60 deg north latitude given by

$$SN\emptyset WN = 60 \text{ deg} - 15 \text{ deg} \cos \left[ \frac{2\pi}{365} (\text{day} - 24.6) \right]$$

where "day" is the number of the day of the year, with day 0 corresponding to 1 January. A constant southern snowline (SN $\emptyset$ WS) is defined at 60 deg south latitude. Although the value of this southern snowline is required by the program for the surface-albedo calculation (see Chapter III, Section H), it actually has no function in defining snow cover, since all land south of 60 deg is permanently ice covered (see Fig. 3.13).

**Table 3.8**

LAND ELEVATION (100 FT)

[illegible]

Table 3.8 (cont.)

## LAND ELEVATION (100 FT)

	90W	85W	80W	75W	70W	65W	60W	55W	50W	45W	40W	35W	30W	25W	20W	15W	10W	5W
90N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
86N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
82N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
78N	19	29	26	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
74N	15	18	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
70N	*	7	5	5	6	*	*	*	*	*	*	*	*	*	*	*	*	*
66N	3	2	*	*	6	5	*	*	*	*	*	*	*	*	*	*	*	*
62N	*	*	*	3	*	*	*	*	*	*	*	*	*	*	*	*	*	*
58N	*	*	*	4	7	6	*	*	*	*	*	*	*	*	*	*	*	2
54N	5	3	*	6	10	9	4	*	*	*	*	*	*	*	*	*	*	3
50N	7	5	6	9	10	8	*	0	*	*	*	*	*	*	*	*	*	*
46N	9	*	9	10	8	4	*	*	*	*	*	*	*	*	*	*	*	*
42N	10	10	11	9	*	*	*	*	*	*	*	*	*	*	*	*	*	14
38N	9	11	10	*	*	*	*	*	*	*	*	*	*	*	*	*	10	18
34N	6	7	5	*	*	*	*	*	*	*	*	*	*	*	*	*	*	21
30N	*	*	1	*	*	*	*	*	*	*	*	*	*	*	*	*	14	22
26N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	12	17
22N	*	*	0	*	*	*	*	*	*	*	*	*	*	*	*	3	8	11
18N	13	*	*	*	0	*	*	*	*	*	*	*	*	*	*	3	7	9
14N	13	11	*	*	*	*	*	*	*	*	*	*	*	*	*	3	7	10
10N	*	*	8	*	19	14	*	*	*	*	*	*	*	*	*	*	6	8
6N	*	*	*	25	29	19	9	*	*	*	*	*	*	*	*	*	*	4
2N	*	*	*	30	26	14	8	4	*	*	*	*	*	*	*	*	*	*
2S	*	*	27	31	19	8	6	5	4	3	*	*	*	*	*	*	*	*
6S	*	*	29	38	25	11	6	7	7	7	6	3	*	*	*	*	*	*
10S	*	*	*	50	48	25	11	9	11	12	9	*	*	*	*	*	*	*
14S	*	*	*	52	67	42	18	12	14	15	11	*	*	*	*	*	*	*
18S	*	*	*	*	64	50	21	13	15	16	9	*	*	*	*	*	*	*
22S	*	*	*	*	56	49	20	11	13	11	*	*	*	*	*	*	*	*
26S	*	*	*	*	51	45	17	8	7	*	*	*	*	*	*	*	*	*
30S	*	*	*	*	43	37	13	4	*	*	*	*	*	*	*	*	*	*
34S	*	*	*	*	31	27	9	2	*	*	*	*	*	*	*	*	*	*
38S	*	*	*	*	22	17	5	*	*	*	*	*	*	*	*	*	*	*
42S	*	*	*	17	20	10	*	*	*	*	*	*	*	*	*	*	*	*
46S	*	*	*	20	18	*	*	*	*	*	*	*	*	*	*	*	*	*
50S	*	*	*	14	14	*	*	*	*	*	*	*	*	*	*	*	*	*
54S	*	*	*	*	6	*	*	*	*	*	*	*	*	*	*	*	*	*
58S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
62S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
66S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
70S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
74S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
78S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
82S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
86S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
90S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

LAND ELEVATION (100 FT)

[illegible]

LAND ELEVATION (100 FT)

[illegible]

Table 3.9

10. FLEETVATION (1000 17)

	180W	175W	170W	165W	160W	155W	150W	145W	140W	135W	130W	125W	120W	115W	110W	105W	100W	95W
90M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*
74M	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*	*	*	*
70M	0	0	0	0	*	*	*	*	0	0	0	0	*	*	*	*	0	*
66M	*	*	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
62M	0	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*
58M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
54M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
50M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
46M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
42M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
38M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2M	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
38S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
42S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
46S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
50S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
54S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
58S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
62S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
66S	0	0	0	0	0	0	0	0	0	0	0	0	0	*	*	*	*	*
70S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74S	0	0	0	0	0	0	0	0	0	0	0	17	16	0	0	0	16	20
78S	0	0	0	0	0	2	6	10	15	21	28	33	32	29	30	35	40	42
82S	0	0	0	0	0	0	20	25	29	34	39	43	46	50	55	61	66	63
86S	50	49	48	47	46	47	49	51	51	53	55	58	63	68	74	78	80	78
90S	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81

Table 3.9 (cont.)

## ICE ELEVATION (100 FT)

	90W	85W	80W	75W	70W	65W	60W	55W	50W	45W	40W	35W	30W	25W	20W	15W	10W	5W
90N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82N	0	23	27	20	13	0	22	31	35	38	34	38	35	31	20	0	0	0
78N	*	*	*	0	0	15	28	43	55	63	66	64	58	47	24	0	0	0
74N	*	*	0	0	0	0	0	33	55	72	78	73	58	40	21	0	0	0
70N	0	*	*	*	*	0	0	0	45	68	70	56	36	0	0	*	*	*
66N	*	*	0	0	*	*	0	*	31	50	43	0	*	*	*	*	*	*
62N	0	0	0	*	0	0	*	*	*	23	*	*	*	*	*	*	*	*
58N	0	0	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
54N	*	*	0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
50N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
46N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
42N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
38N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
38S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
42S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
46S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
50S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
54S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
58S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
62S	*	*	*	*	*	*	0	0	0	0	0	0	0	0	0	0	0	0
66S	*	*	*	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0
70S	0	0	0	0	22	23	0	0	0	0	0	0	0	0	0	0	0	0
74S	20	16	12	16	26	26	0	0	0	0	0	0	0	0	27	38	44	53
78S	39	30	22	19	21	18	0	0	0	0	0	0	0	0	27	38	44	53
82S	57	46	36	30	29	28	26	25	25	27	30	36	45	55	65	74	81	86
86S	73	65	59	56	55	56	57	57	58	59	61	65	69	73	77	81	84	87
90S	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81



**Table 3.9 (cont.)**

## ICE ELEVATION (100 FT)

	0	5F	10F	15F	20F	25F	30F	35F	40F	45F	50F	55F	60F	65F	70F	75F	80F	85F
90N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78N	0	*	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74N	*	*	*	*	*	*	*	*	*	*	0	*	0	0	0	0	0	0
70N	*	*	*	*	*	*	*	*	*	*	0	*	*	0	*	*	*	*
66N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
62N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
58N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
54N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
50N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
46N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
42N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
38N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
38S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
42S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
46S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
50S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
54S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
58S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66S	0	0	0	0	0	0	0	0	0	0	26	26	0	0	0	0	0	0
70S	30	38	40	42	42	43	44	47	51	56	61	58	46	45	42	37	48	57
74S	64	73	77	79	80	82	84	87	90	92	90	85	75	66	65	73	85	95
78S	86	92	96	99	101	103	106	108	109	109	106	102	96	94	94	100	106	111
82S	90	94	97	100	103	106	108	109	110	111	110	108	107	107	109	111	112	113
86S	89	91	92	94	96	98	99	100	101	102	102	102	103	103	106	104	104	104
90S	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81

Table 3.9 (cont.)

## ICE ELEVATION (100 FT)

	90E	95E	100E	105E	110E	115E	120E	125E	130E	135E	140E	145E	150E	155E	160E	165E	170E	175E
90N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
86N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78N	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
74N	*	*	*	*	*	0	0	0	0	0	0	0	0	0	0	0	0	0
70N	*	*	*	*	*	*	*	*	*	*	*	*	*	0	0	0	0	0
66N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0	0	0	0
62N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
58N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0
54N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
50N	*	*	*	*	*	*	*	*	*	*	*	*	*	0	*	*	*	*
46N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
42N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
38N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2N	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
10S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
14S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
18S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
22S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
26S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
30S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
34S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
38S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
42S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
46S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
50S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
54S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
58S	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
62S	0	0	0	0	0	0	0	*	*	*	*	0	0	*	*	*	*	*
66S	0	29	32	28	0	0	0	0	28	27	0	0	0	0	0	0	0	0
70S	64	69	70	66	60	58	58	60	63	61	53	45	39	32	22	0	0	0
74S	100	101	99	96	93	92	91	89	88	86	78	71	65	56	39	16	0	0
78S	113	113	111	108	104	102	99	97	93	89	84	79	74	66	46	0	0	0
82S	113	112	110	107	104	101	99	96	93	89	86	82	78	71	51	0	0	0
86S	103	102	101	99	97	96	95	93	91	90	88	85	83	79	69	57	52	50
90S	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81	81

Table 3.10

SEA-SURFACE TEMPERATURE (DEG C)

	180W	175W	170W	165W	160W	155W	150W	145W	140W	135W	130W	125W
90N	*	*	*	*	*	*	*	*	*	*	*	*
86N	*	*	*	*	*	*	*	*	*	*	*	*
82N	*	*	*	*	*	*	*	*	*	*	*	*
78N	*	*	*	*	*	*	*	*	*	*	*	*
74N	*	*	*	*	*	*	*	*	*	*	*	*
70N	*	*	*	*	*	*	*	*	*	*	*	*
66N	*	*	*	*	*	*	*	*	*	*	*	*
62N	*	*	*	*	*	*	*	*	*	*	*	*
58N	3.1	3.4	3.8	4.6	5.2	*	7.1	7.6	7.6	*	*	*
54N	4.2	4.6	5.1	*	6.5	7.2	8.1	9.0	9.5	8.9	*	*
50N	5.7	6.0	6.5	7.2	7.7	8.5	9.3	10.0	10.5	10.6	10.5	*
46N	7.9	8.2	8.8	9.5	10.0	10.6	11.3	11.8	12.3	12.5	12.3	11.5
42N	11.3	11.4	11.9	12.5	12.8	13.3	13.8	14.1	14.3	14.2	13.6	12.0
38N	15.4	15.4	15.3	15.5	15.7	15.9	16.2	16.3	16.1	15.5	14.5	12.5
34N	18.8	18.6	18.6	18.6	18.7	18.8	18.8	18.6	17.9	17.1	16.1	14.7
30N	21.5	21.3	21.2	21.2	21.0	21.0	20.9	20.3	19.6	18.8	17.9	17.1
26N	24.0	23.8	23.5	23.3	23.1	22.9	22.5	21.8	21.3	20.5	19.8	19.2
22N	25.3	25.1	24.8	24.5	24.2	23.9	23.5	22.9	22.3	21.7	21.0	20.7
18N	26.4	26.2	25.8	25.6	25.2	24.9	24.6	24.0	23.6	23.2	23.0	23.2
14N	26.9	26.7	26.5	26.2	26.0	25.8	25.6	25.2	24.8	24.7	24.7	25.2
10N	27.4	27.3	27.1	27.0	26.8	26.6	26.5	26.3	26.1	26.1	26.3	26.6
6N	27.6	27.5	27.3	27.1	26.9	26.9	26.8	26.8	26.7	26.8	26.8	26.8
2N	27.8	27.5	27.2	27.0	26.7	26.5	26.5	26.5	26.1	26.0	25.8	25.5
2S	27.9	27.5	27.2	26.9	26.5	26.3	26.0	25.9	25.6	25.4	24.5	24.3
6S	28.2	28.0	27.8	27.6	27.4	27.2	26.9	26.7	26.5	26.2	25.9	25.4
10S	28.2	28.1	27.9	27.7	27.5	27.3	27.2	27.1	26.8	26.5	26.1	25.8
14S	27.3	27.4	27.4	27.2	27.0	26.9	26.7	26.6	26.5	26.3	26.2	25.7
18S	25.9	25.9	26.0	25.9	25.8	25.8	25.8	25.6	25.5	25.4	25.3	25.2
22S	24.2	24.2	24.2	24.3	24.3	24.3	24.2	24.2	24.2	24.1	24.1	23.9
26S	22.2	22.4	22.5	22.5	22.6	22.6	22.6	22.6	22.6	22.5	22.5	22.4
30S	19.9	20.0	20.1	20.1	20.2	20.2	20.2	20.2	20.2	20.2	20.1	20.1
34S	17.9	18.1	18.1	18.0	17.9	17.9	17.6	17.6	17.6	17.6	17.6	17.5
38S	16.2	16.3	16.2	16.0	15.5	15.0	14.8	14.7	14.5	14.4	14.4	14.5
42S	14.6	14.8	14.7	14.3	13.4	13.0	12.7	12.4	12.3	12.3	12.3	12.3
46S	12.4	12.5	12.6	12.6	11.6	11.1	10.7	10.5	10.3	10.2	10.1	10.1
50S	8.0	9.0	10.2	10.2	9.5	8.9	8.3	7.8	7.7	7.5	7.4	7.3
54S	5.5	6.1	6.8	7.0	6.7	6.3	5.7	5.3	5.0	4.6	4.6	4.6
58S	2.8	3.0	3.1	3.1	2.9	2.6	2.4	2.1	1.6	1.2	1.1	1.3
62S	-0.1	0.1	0.1	-0.1	-0.1	-0.5	-0.6	-0.6	-0.6	-0.7	-0.6	-0.6
66S	*	*	*	*	*	*	*	*	*	*	*	*
70S	*	*	*	*	*	*	*	*	*	*	*	*
74S	*	*	*	*	*	*	*	*	*	*	*	*
78S	*	*	*	*	*	*	*	*	*	*	*	*
82S	*	*	*	*	*	*	*	*	*	*	*	*
86S	*	*	*	*	*	*	*	*	*	*	*	*
90S	*	*	*	*	*	*	*	*	*	*	*	*

Table 3.10 (cont.)

## SEA-SURFACE TEMPERATURE (DEG C)

[illegible]

Table 3.10 (cont.)

## SFA-SURFACE TEMPERATURE (DEG C)

[illegible]

Table 3.10 (cont.)

SEA-SURFACE TEMPERATURE (DEG C)

[illegible]

Table 3.10 (cont.)

SFA-SURFACE TEMPERATURE (DEG C)

[illegible]

[illegible]



#### IV. MODEL PERFORMANCE

##### A. OPERATING CHARACTERISTICS

###### 1. Integration Program

The Mintz-Arakawa two-level model is written in IBM FORTRAN IV (see program listing, Chapter VII). The core size, central processing unit (CPU) time, and the input/output (I/O) requirements are based on experience with the FORTRAN H compiler on an IBM 360/91 at UCLA for a 46-by-72 array. The model uses about 400,000 bytes of core memory, and each simulated day requires about 25 minutes of CPU time and about 1000 I/O requests. All calculations are performed with single-precision arithmetic.

The program in its present form is expected to start from nonzero initial data, and the history-restart tape is used to provide the initial values for continuing the calculations. The time to restart is specified by the parameters TAUID and TAUIH (see the control-card sequence below). The tape is read until the last record is reached or until TAU from tape (expressed in hours) is less than or equal to  $TAUIH + 24 \cdot TAUID$ . If the last record on the tape (identified by -TAU) is reached before the specified time to restart, the last set of data will be used. This allows automatic continuation of the calculation from the last time data were stored on the tape.

The input parameters TRST and TERM control the disposition of the old and new sets of data. If  $TRST = 0$ , the newly computed data will be written on the old history-restart tape as if no interruption had occurred; otherwise, the new data are written at the beginning of a different tape. If  $TRST \neq 0$ , the parameter TERM determines whether the old history-restart tape is to be terminated after the restart data are read from it. If  $TERM = 0$ , the old tape is not terminated. The data-set reference number of the tape to be written is always 11. If  $TRST \neq 0$ , the initial data is read from data-set reference number 10.

Various control parameters and constants in the program are read from cards, although several of the parameters that are read in the

model's present version no longer influence the program. The topography deck following card number fourteen (MARK) is read only if a change is desired in sea-surface temperature, land elevation, or the assigned distribution of ice. All numerical values follow the standard FORTRAN convention except KAPA, which is a real number. Only the constants NCYCLE, NC3, JM, IM, MARK, LDAY, LYR, and the sequence numbers in the topography deck are in integer format. The control-card sequence and layout are as follows:

<u>Card Number</u>	<u>Name</u>	<u>Card Columns</u>	<u>Units</u>	<u>Description</u>
1	ID	1-4	--	Four-character identifier
1	XLABL	5-40	--	Thirty-six-character identifier
2	TAUID	1-10	day	Day to start
2	TAUIH	11-20	hour	Hour to start
2	TRST	21-30	--	Output-tape control parameter
2	TERM	31-40	--	Output-tape control parameter
3	TAUO	1-10	--	Not used
3	TAUD	11-20	hour	Frequency to recompute solar declination
3	TAUH	21-30	hour	Frequency to write history-restart tape
3	TAUE	31-40	day	Time to stop computation
3	TAUC	41-50	--	Not used
4	DTM	1-10	min	Time step
4	NCYCLE	11-15	IS <sup>(1)</sup>	Time extrapolation control parameter
4	NC3	16-20	IS <sup>(1)</sup>	Frequency to call COMP 4 and COMP 3
5	JM	1-5	--	Number of N-S grid points (in $\pi$ grid)
5	IM	6-10	--	Number of E-W grid points (in $\pi$ grid)
5	DLAT	11-20	deg	Distance between N-S grid points
6	AX	1-10	--	Diffusion coefficient (not used)

(1) The IS unit is one integration time step.

<u>Card Number</u>	<u>Name</u>	<u>Card Columns</u>	<u>Units</u>	<u>Description</u>
7	FMX	1-10	$10^{-5} \text{ sec}^{-1}$	Shear-stress coefficient
7	ED	11-20	m	Constant used in air/ground interaction
7	TCNV	21-30	sec	Relaxation time for cumulus convection
8	RAD	1-10	km	Earth radius, a
8	GRAV	11-20	$\text{m sec}^{-2}$	Gravitational acceleration, g
8	DAY	21-30	hour	Length of day
9	RGAS	1-10	$\text{m}^2 \text{ deg}^{-1} \text{ sec}^{-2}$	Gas constant, R
9	KAPA	11-20	--	Thermodynamic coefficient, $\kappa$
10	PSL	1-10	mb	Sea-level pressure
10	PTRØP	11-20	mb	Tropospheric pressure, $p_T$
11	PSF	1-10	mb	Surface pressure, $p_s$
12	DLIC	1-10	--	Not used
13	KSET	1-10	--	Not used
14	MARK	1-3	--	Flag indicating presence of topography deck (sea-surface temperature and land elevation) and number of sets of cards to be read. In 46-by-72 grid version, MARK = 72.
15-376	Topography Deck -- see description below.			
377	CLKSW	1-4	--	If the characters ØFF are punched in columns 1 to 3 with column 4 blank, the solar declination will remain fixed.
377	RSETSW	11-14	--	If the characters RESE are punched in columns 1 to 4, the day and year counters (SDEDY and SDEYR) will be set to LDAY and LYR.
377	LDAY	21-23	day	Day of year if time is reset
377	LYR	31-34	year	Year if time is reset

The topography deck is read only if MARK  $\neq$  0. The deck contains 2 + 5 · MARK cards and is read in subroutine INIT 2. The topography deck card layout is as follows:

<u>Number of Cards</u>	<u>Name</u>	<u>Description</u>
1	TEMSCL	Four characters in columns 1 to 4. Indicates temperature scale of sea-surface temperature: FAHR = Fahrenheit, CENT = centigrade.
3•MARK	Sea-surface temperature	'MARK' is the number of three-card sets that define the ocean temperature for each longitude, beginning at the south pole and extending north. For the 46-by-72 grid, the numbers each take four columns (a decimal point is implicit between the third and fourth columns), with fifteen numbers on the first and second cards and sixteen numbers on the third card. The longitude grid number (i = 1-72) is in columns 79 and 80 of each card of a set, and must be sequential. Special numbers indicate points that are not open ocean: -640 for land without ice, and -960 for land ice or sea ice.
1	HSCL	Four characters in columns 1 to 4. Indicates distance scale of land elevation: FEET = feet/100, METE = meters/10.
2•MARK	Land elevation	'MARK' is here the number of two-card sets that define the land elevation for each longitude, beginning at the south pole and extending north. For the 46-by-72 grid, the numbers each take three columns (a decimal point is implicit following the third column), with twenty-five numbers on the first card and twenty-one numbers on the second card. The longitude grid number (i = 1-72) is in columns 79 and 80 of each card of a set, and must be sequential. The elevations must be in either hundreds of feet or tens of meters. The entries in this deck corresponding to sea surface must be zero or blank.

The principal output of the model is written on magnetic tape, and a history-restart tape is written at specified intervals. Eighteen logical records are written with a frequency of TAUH: TAU and C, P, U, V, T, Q3, TOPOG, PT, GW, TS, GT, SN, TT, Q3T, SD, H, TD, -TAU and C. These arrays contain all constants and current variables, and in addition, several arrays of packed data generated in subroutine COMP 3. [Note

that TS is equivalent to UT(1,1,2) and SN is equivalent to VT(1,1,2) in the data from subroutine COMP 3.]<sup>†</sup> In the present version of the model these records are written on tape every 6 hours (= TAUH). The last logical record (-TAU,C) is identified as the last record written on the tape, and will be written over the next time the tape is written; hence, only seventeen records are saved every TAUH. A test is made before writing the tape to determine if it is properly positioned. About sixty sets of seventeen logical records can be saved on a 2400-ft reel of tape. The automatically printed output consists of the input parameters, the time at each integration step, and the amount of pressure added at each grid point every twenty-four hours of simulated time in the subroutine GMP.

## 2. Map-Generation Program

The map-generation program for use with the model uses about 520,000 bytes of core, and averages about 0.2 seconds of CPU time and about 5 I/O requests for each map generated. This program reads the data produced by the model and processes them to form arrays of data in map form. The source of the basic data may be tape or disk.

The tape input format is the same as the tape output from the model: TAU and C, P, U, V, T, Q3, TØPØG, PT, GW, TS, GT, SN, TT, Q3T, SD, H, TD. The first logical record on a disk is always TØPØG, which does not change during a run. The subsequent logical records for each time step that was saved are TAU and C, P, U, V, T, Q3, PT, GW, TS, GT, SN, TT, Q3T, SD.

The card input to the map-generation program consists of an interval and data-source control card, followed by as many as ninety-nine map selection cards. The end of the map selection card deck is indicated by a blank card. The interval and data-source control card contains TØ (the time, in days, to start generating the map arrays), TEND (the time, in days, to stop generating the map arrays), and TAPIN (the data-source indicator). The card layout is as follows:

---

<sup>†</sup> Some arrays may be referred to by different names. For example, Q(J,I,K) contains  $\pi$ , U1, U3, V1, V3, T1, T3, and Q3 for K = 1 through 8. See the common and equivalence block in Chapter VII for more detail.

<u>Parameter</u>	<u>Card Columns</u>
TØ	1-10
TEND	11-20
TAPIN	21-24

The desired maps will be generated for TØ, TEND, and for each intermediate time available from the data source. If the characters TAPE are punched in columns 21 to 24 (TAPIN), the data source is a tape; otherwise the source is assumed to be a disk.

The map selection cards contain MAPNØ (the map number) and SURF (the  $\sigma$  surface,  $< 2.0$ , or the pressure level, in millibars, at which the map is to be calculated). The card layout is as follows:

<u>Parameter</u>	<u>Card Columns</u>
MAPNØ	1-2
SURF	3-12

Some values of SURF are not valid for certain maps, and in some cases the following convention has been used:

topography maps: SURF  $< 2.0$  for ocean temperature  
SURF  $\geq 2.0$  for surface elevation  
cloudiness maps: SURF  $\leq 0.5$  for high cloudiness  
SURF = 1.0 for low cloudiness  
 $0.5 < \text{SURF} \neq 1.0$  for middle cloudiness  
SURF  $> 1.0$  for cloudiness (maximum)

The processed data representing each requested map array are written on tape along with various other data, and the tape may be used for further processing and map displays. The map array is dimensioned (JM, IM), where JM is the total number of north/south grid points and IM is the total number of east/west grid points. One logical

record is written for each map, and contains the following data:

<u>Name and Dimension</u>	<u>Description</u>
TAU (1)	Time in hours
ID (1)	Four-character identification from the model
MAPNØ (1)	Map number
NAME (13)	Map title
SURF (1)	Sigma surface or pressure level for which the map is generated
STAGI (1){ STAGJ (1){	Logical variables indicating whether the maps are staggered (offset) in the I and J directions
SINT (1)	Not used in the present version
WØRK2 (JM,IM)	Map array
ZM (JM)	Zonal mean
ZM2 (JM)	Zonal mean, excluding points on land or ice
ZMM (1)	Global mean

The printed output consists of the input parameters, along with the map time, number, surface or level, and map title of each record as written on the tape.

## B. SAMPLE MODEL OUTPUT

### 1. Maps of Selected Variables

To illustrate the general nature and structure of the solutions of the circulation model, a series of programmed map outputs for selected variables has been developed (see Map Routine Listing in Chapter VII). Presented here are samples of this output for the primary dependent variables  $p_s$ ,  $u_1$ ,  $u_3$ ,  $v_1$ ,  $v_3$ ,  $T_1$ ,  $T_3$ , and  $q_3$  (as represented by the relative humidity), and for the geopotential heights. A selection of variables related to the heat and water balance in the model layers and at the surface is also given. These data are for day 400 (28 January, hour 0 GMT) of a basic or control simulation of

northern-hemisphere winter, with the program as listed in Chapter VII and with the fixed sea-surface temperature and ice distributions as shown in Chapter III.

For each of the maps shown below, a brief identification and description of the mapped quantity is given on the facing page, while the values of the minimum and dashed isolines and of the isoline interval are given at the upper right of each map's label. The symbols H and L designate locations of local maxima and minima, respectively, that are not resolved by the selected isoline interval. A rectangular map representation of the spherical grid has been used for convenience, with the points of the  $\pi$  grid and continental outlines shown as in Fig. 3.12. For each map the designation S/P denotes the  $\sigma$  level of the map, with S/P = 1 for those maps without a level designation as well as for the surface. The velocity, temperature, and geopotential heights may be generated for any  $0 \leq \sigma \leq 1$  by extrapolation and interpolation from the solutions at  $\sigma = 1/4$  and  $\sigma = 3/4$ , and may also be displayed for any pressure surface  $p_T \leq p \leq p_S$  (see Map Routine Listing, Chapter VII). The complete list of available maps is given in Chapter VII just before the map code listings

Those maps listed in Table 4.1 are given in  $\sigma$  coordinates, with the exception of the geopotential height in Map 6, which is given for both  $\sigma$  and  $p$  surfaces.



Table 4.1  
LIST OF MAPS OF SELECTED VARIABLES

Map	Title
1	Smoothed sea-level pressure ( $\sigma = 1$ )
2	Zonal (west/east) wind component ( $\sigma = 1/4, 3/4$ )
3	Meridional (south/north) wind component ( $\sigma = 1/4, 3/4$ )
4	Temperature ( $\sigma = 1/4, 3/4$ )
6	Geopotential height ( $\sigma = 1/4, 3/4$ ; $p = 400, 800$ mb)
8	Total diabatic heating ( $\sigma = 1/4, 3/4$ )
9	Large-scale precipitation rate
10	Sigma vertical velocity ( $\sigma = 1/2$ )
11	Relative humidity ( $\sigma = 3/4$ )
12	Precipitable water
13	Convective precipitation rate
14	Evaporation rate ( $\sigma = 1$ )
15	Sensible heat flux ( $\sigma = 1$ )
16	Lowest-level convection ( $\sigma = 1$ )
19	Long-wave heating in layers ( $\sigma = 0$ to $1/2$ , $\sigma = 1/2$ to $1$ )
20	Short-wave absorption (heating) in layers ( $\sigma = 0$ to $1/2$ , $\sigma = 1/2$ to $1$ )
22	Surface short-wave absorption ( $\sigma = 1$ )
23	Surface air temperature ( $\sigma = 1$ )
24	Ground temperature ( $\sigma = 1$ )
25	Ground wetness ( $\sigma = 1$ )
26	Cloudiness (high, middle, low)
28	Total convective heating in layers ( $\sigma = 0$ to $1/2$ , $\sigma = 1/2$ to $1$ )
29	Latent heating ( $\sigma = 1/2$ to $1$ )
30	Surface long-wave cooling ( $\sigma = 1$ )
31	Surface heat balance ( $\sigma = 1$ )

Fig. 4.1. Smoothed Sea-Level Pressure (Map 1)

(mb - 1000 mb)

This map is calculated from the expression

$$p_s \exp\left(\frac{\phi_4}{R\bar{T}}\right) - 1000 \text{ mb}$$

where  $p_s$  is the surface pressure,  $\phi_4$  is the geopotential at the ground,  $R$  is the dry-air gas constant, and  $\bar{T}$  is the average temperature between level 4 and sea level, given by

$$\bar{T} = T_4 + \frac{1}{2} \frac{\gamma \phi_4}{g}$$

Here  $T_4 = \frac{3}{2} T_3 - \frac{1}{2} T_1$  is the air temperature extrapolated to the surface,  $g$  is acceleration of gravity, and  $\gamma$  is an assumed constant lapse rate in the hypothetical layer between the earth's surface and sea level, taken here as  $\gamma = 0.6 \text{ deg C/100 m}$ . The resulting sea-level pressures are then averaged over the local 9 points at which pressure is computed. At nonpolar points this smoothing operator is

$$\begin{aligned} ( )_{00, \text{smoothed}} = & \frac{1}{16} \left[ ( )_{-22} + 2( )_{02} \right. \\ & + ( )_{22} + 2( )_{-20} + 4( )_{00} + 2( )_{20} \\ & \left. + ( )_{-2-2} + 2( )_{0-2} + ( )_{2-2} \right] \end{aligned}$$

where the subscripts (in  $\pi$ -centered notation) refer to adjacent points of the  $\pi$  grid (see Fig. 3.6).

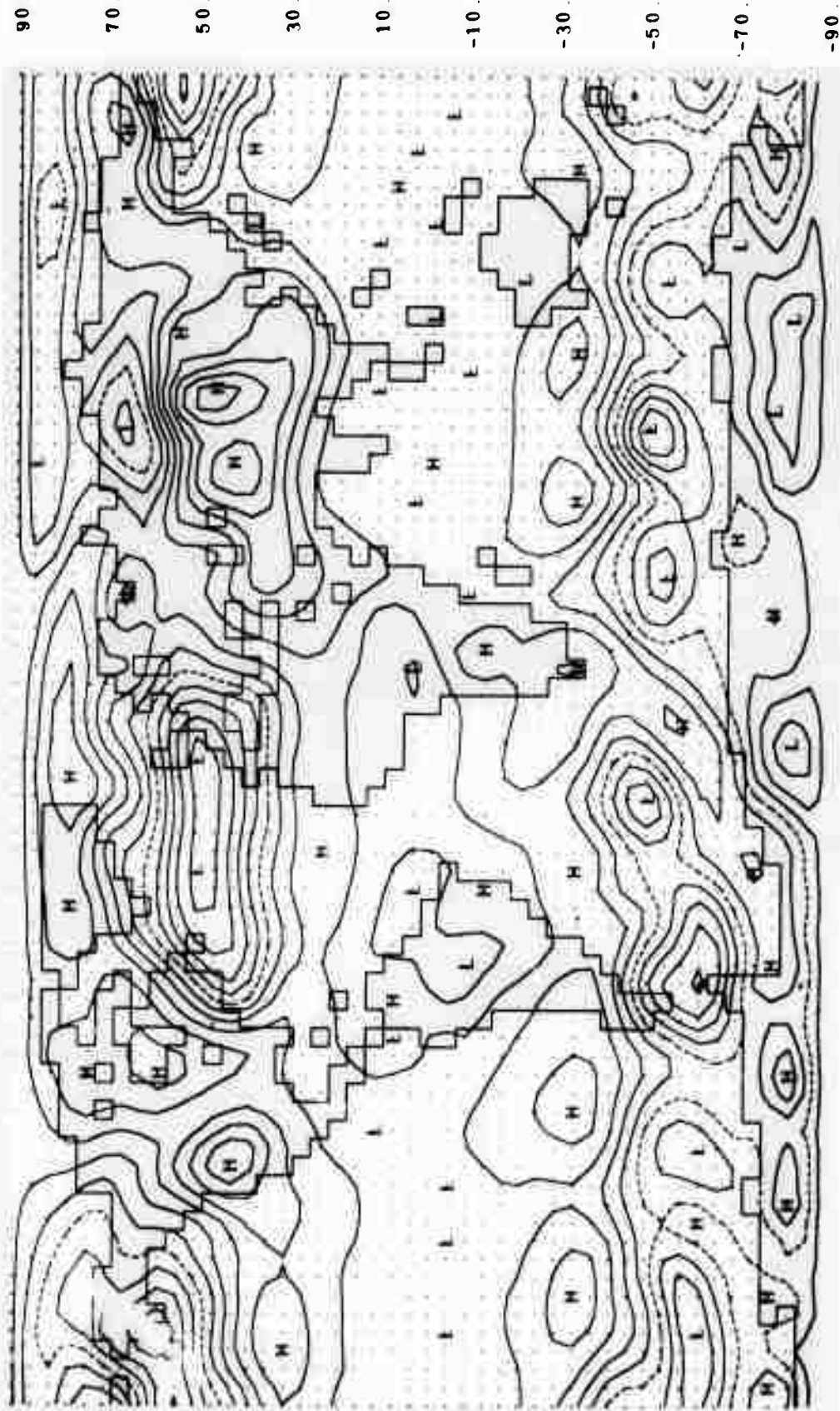


Fig. 4.1 -- Smoothed sea-level pressure. The dashed line is 1000 mb and the isoline interval is 5 mb.

Fig. 4.2. Zonal (West/East) Wind Component (Map 2)

(m sec<sup>-1</sup>)

This map is calculated from the expression

$$u = 2 \left[ u_3 \left( \sigma - \frac{1}{4} \right) + u_1 \left( \frac{3}{4} - \sigma \right) \right]$$

with  $0 \leq \sigma \leq 1$  an arbitrary  $\sigma$  surface. For  $\sigma = 1/4$  and  $\sigma = 3/4$  this reduces to the primary variables  $u_1$  and  $u_3$ , respectively, and for other  $\sigma$  represents a linear extrapolation and interpolation of  $u$  in  $\sigma$  (or  $p$ ) space. The zonal wind component may also be generated for an arbitrary pressure surface  $p$ , in which case  $\sigma$  in the above expression is replaced by  $(p - p_T)/(\pi^u)$ , where  $\pi^u$  is the average of  $\pi$  at the four  $\pi$  points surrounding each  $u, v$  point. The symbols E and W designate locations of local maxima of positive (eastward) and negative (westward) zonal wind speed, respectively, which are not resolved by the selected isoline interval.

Level shown in map at right:  $\sigma = 1/4$ .

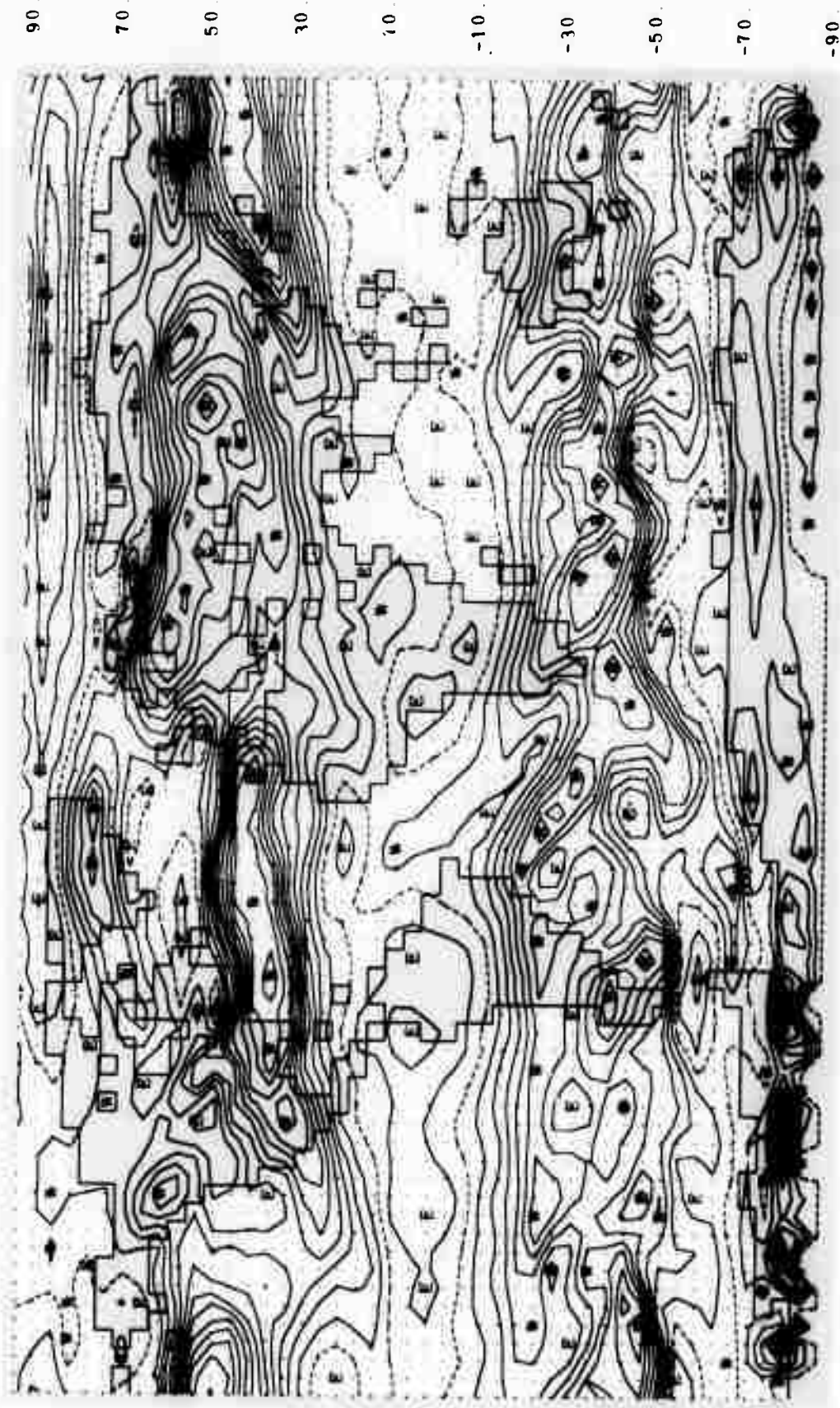


Fig. 4.2 -- Zonal ( $u$ ) wind speed at  $v = 1/4$ . The dashed line is 0 and the isoline interval is  $5 \text{ m sec}^{-1}$ .

Fig. 4.3. Zonal (West/East) Wind Component (Map 2)

(m sec<sup>-1</sup>)

This map is calculated from the expression

$$u = 2 \left[ u_3 \left( \sigma - \frac{1}{4} \right) + u_1 \left( \frac{3}{4} - \sigma \right) \right]$$

with  $0 \leq \sigma \leq 1$  an arbitrary  $\sigma$  surface. For  $\sigma = 1/4$  and  $\sigma = 3/4$ , this reduces to the primary variables  $u_1$  and  $u_3$ , respectively, and for other  $\sigma$  represents a linear extrapolation and interpolation of  $u$  in  $\sigma$  (or  $p$ ) space. The zonal wind component may also be generated for an arbitrary pressure surface  $p$ , in which case  $\sigma$  in the above expression is replaced by  $(p - p_T)/(\pi^u)$ , where  $\pi^u$  is the average of  $\pi$  at the four  $\pi$  points surrounding each  $u, v$  point. The symbols E and W designate locations of local maxima of positive (eastward) and negative (westward) zonal wind speed, respectively, which are not resolved by the selected isoline interval.

Level shown in map at right:  $\sigma = 3/4$ .

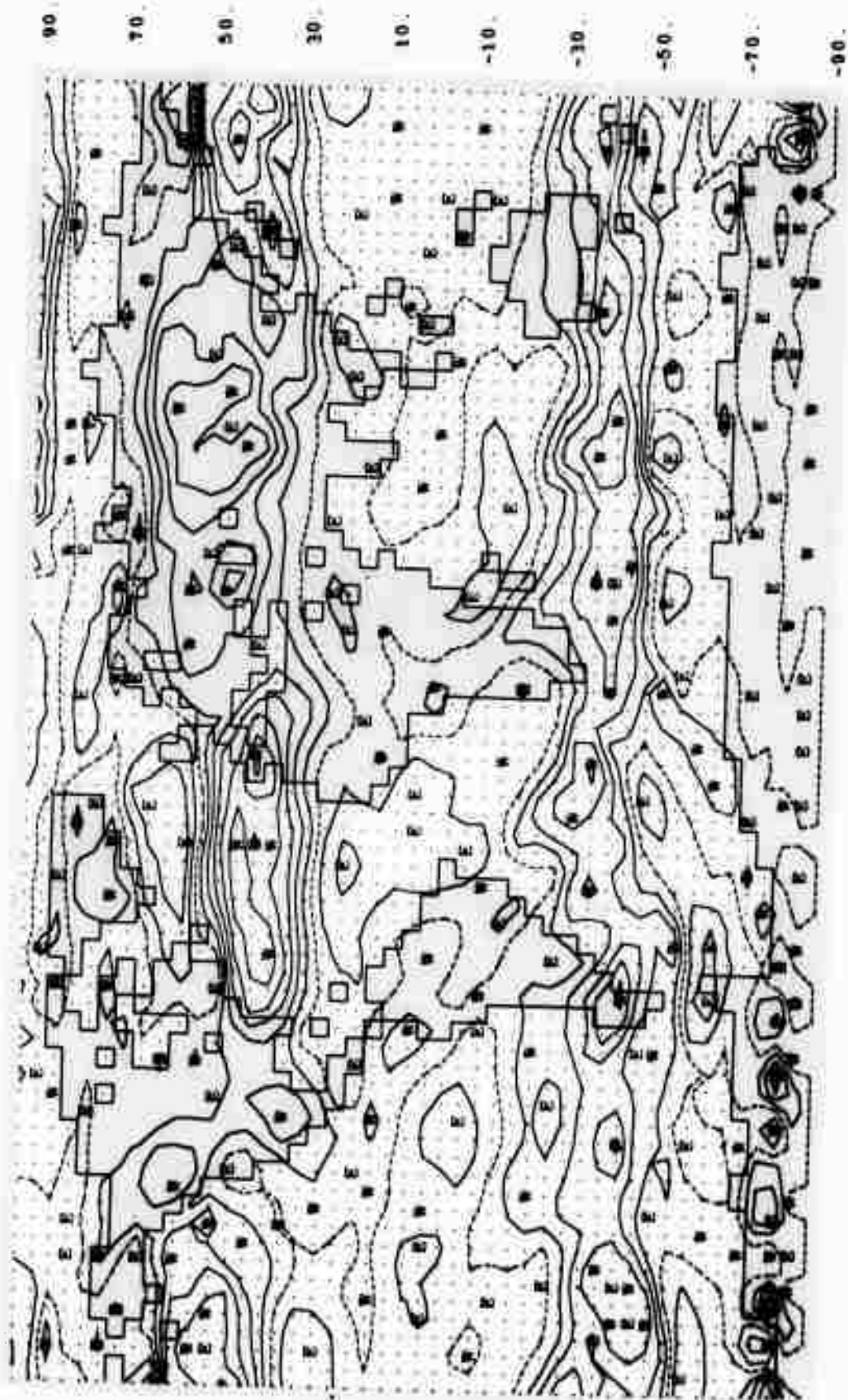


Fig. 4.3 -- Zonal (u) wind speed at  $\tau = 3/4$ . The dashed line is 0 and the isoline interval is 5  $\text{m/sec}$ .

Fig. 4.4. Meridional (South/North) Wind Component (Map 3)  
(m sec<sup>-1</sup>)

The map is calculated from the expression

$$v = 2 \left[ v_3 \left( \sigma - \frac{1}{4} \right) + v_1 \left( \frac{3}{4} - \sigma \right) \right]$$

with  $0 \leq \sigma \leq 1$  an arbitrary  $\sigma$  surface. For  $\sigma = 1/4$  and  $\sigma = 3/4$ , this reduces to the primary variables  $v_1$  and  $v_3$ , respectively, and for other  $\sigma$  represents a linear extrapolation and interpolation of  $v$  in  $\sigma$  (or  $p$ ) space. The meridional wind component may also be generated for an arbitrary pressure surface  $p$ , in which case  $\sigma$  in the above expression is replaced by  $(p - p_T)/(\pi^u)$ , where  $\pi^u$  is the average of  $\pi$  at the four  $\pi$  points surrounding each  $u, v$  point. The symbols  $N$  and  $S$  designate locations of local maxima of positive (northward) and negative (southward) meridional wind speed, respectively, which are not resolved by the selected isoline interval.

Level shown in map at right:  $\sigma = 1/4$ .



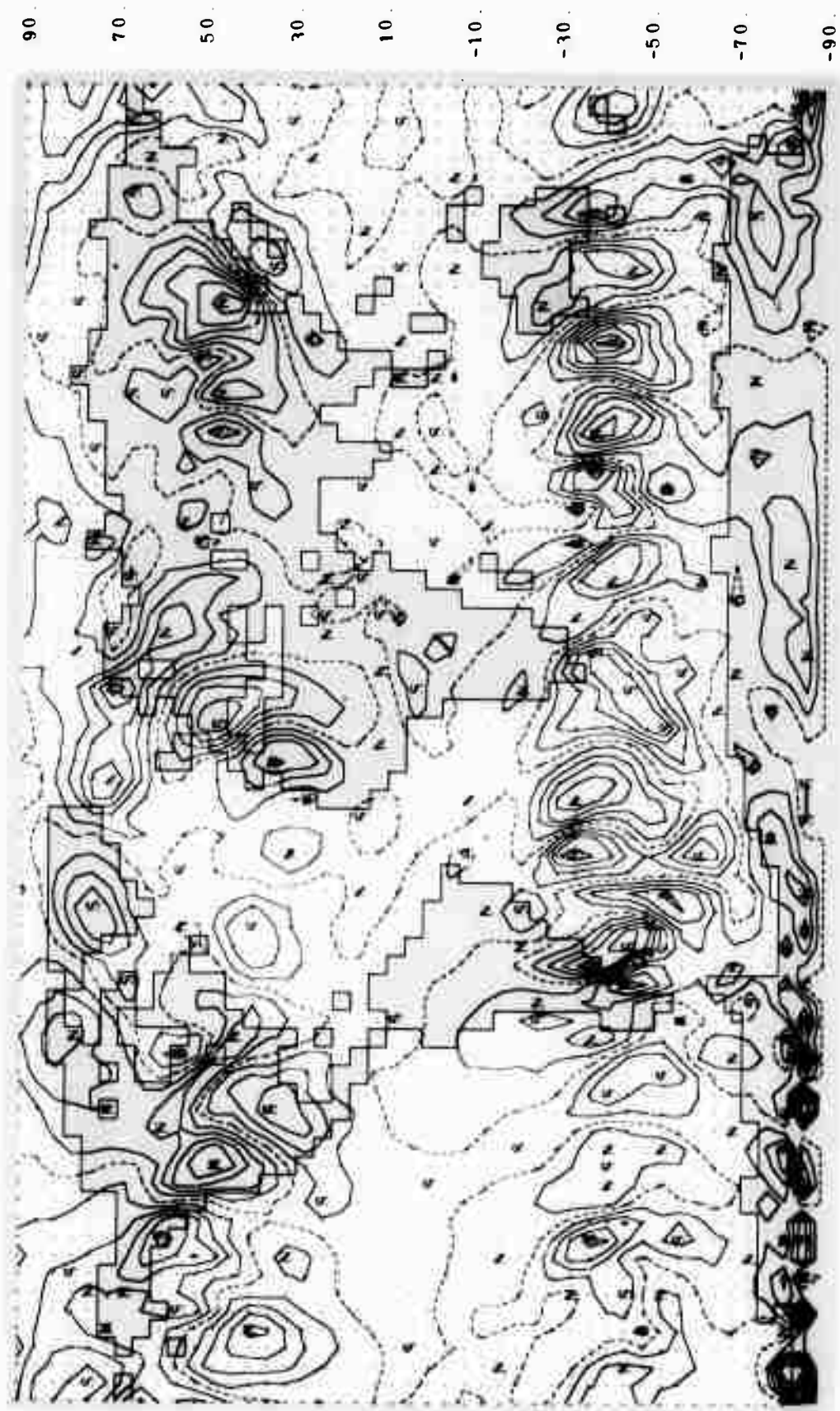


Fig. 4.4 -- Meridional ( $v$ ) wind speed at  $\sigma = 1/4$ . The dashed line is 0 and the isoline interval is  $5 \text{ m sec}^{-1}$ .

Fig. 4.5. Meridional (South/North) Wind Component (Map 3)

(m sec<sup>-1</sup>)

This map is calculated from the expression

$$v = 2 \left[ v_3 \left( \sigma - \frac{1}{4} \right) + v_1 \left( \frac{3}{4} - \sigma \right) \right]$$

with  $0 \leq \sigma \leq 1$  an arbitrary  $\sigma$  surface. For  $\sigma = 1/4$  and  $\sigma = 3/4$ , this reduces to the primary variables  $v_1$  and  $v_3$ , respectively, and for other  $\sigma$  represents a linear extrapolation and interpolation of  $v$  in  $\sigma$  (or  $p$ ) space. The meridional wind component may also be generated for an arbitrary pressure surface  $p$ , in which case  $\sigma$  in the above expression is replaced by  $(p - p_T)/(\pi^u)$ , where  $\pi^u$  is the average of  $\pi$  at the four  $\pi$  points surrounding each  $u, v$  point. The symbols N and S designate locations of local maxima of positive (northward) and negative (southward) meridional wind speed, respectively, which are not resolved by the selected isoline interval.

Level shown in map at right:  $\sigma = 3/4$ .

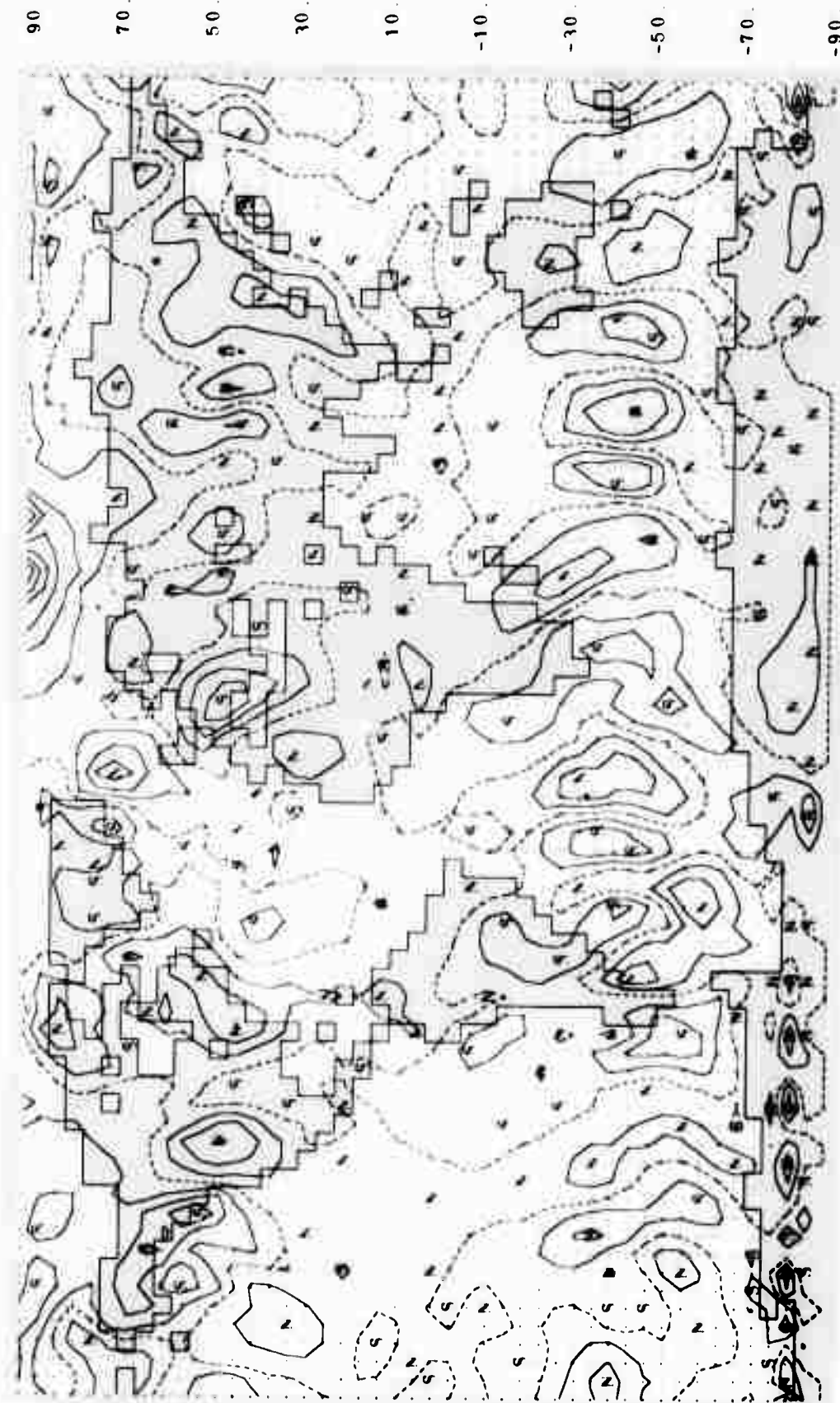


Fig. 4.5 -- Meridional ( $v$ ) wind speed at  $\tau = 3/4$ . The dashed line is 0 and the isoline interval is 5  $\text{m sec}^{-1}$ .

Fig. 4.6. Temperature (Map 4)

(deg C)

This map is calculated from the expression

$$T = \frac{(\sigma\pi + p_T)^\kappa}{p_3^\kappa - p_1^\kappa} \left\{ \frac{T_1}{p_1^\kappa} [p_3^\kappa - (\sigma\pi + p_T)^\kappa] + \frac{T_3}{p_3^\kappa} [(\sigma\pi + p_T)^\kappa - p_1^\kappa] \right\} - 273.1 \text{ deg}$$

with  $0 \leq \sigma \leq 1$  an arbitrary  $\sigma$  surface. This represents the linear interpolation and extrapolation of the potential temperature  $\theta = T(p_0/p)^\kappa$  in  $p^\kappa$  space. For  $\sigma = 1/4$  and  $\sigma = 3/4$ , this reduces to the primary variables  $T_1$  and  $T_3$ , respectively. Here  $p_T$  is the tropopause pressure ( $\approx 200$  mb) and  $\kappa = 0.286$ . The temperature may also be obtained at an arbitrary pressure surface  $p_T \leq p \leq p_s = \pi + p_T$  by replacing  $(\sigma\pi + p_T)$  in the above expression by  $p$ .

Level shown in map at right:  $\sigma = 1/4$ .

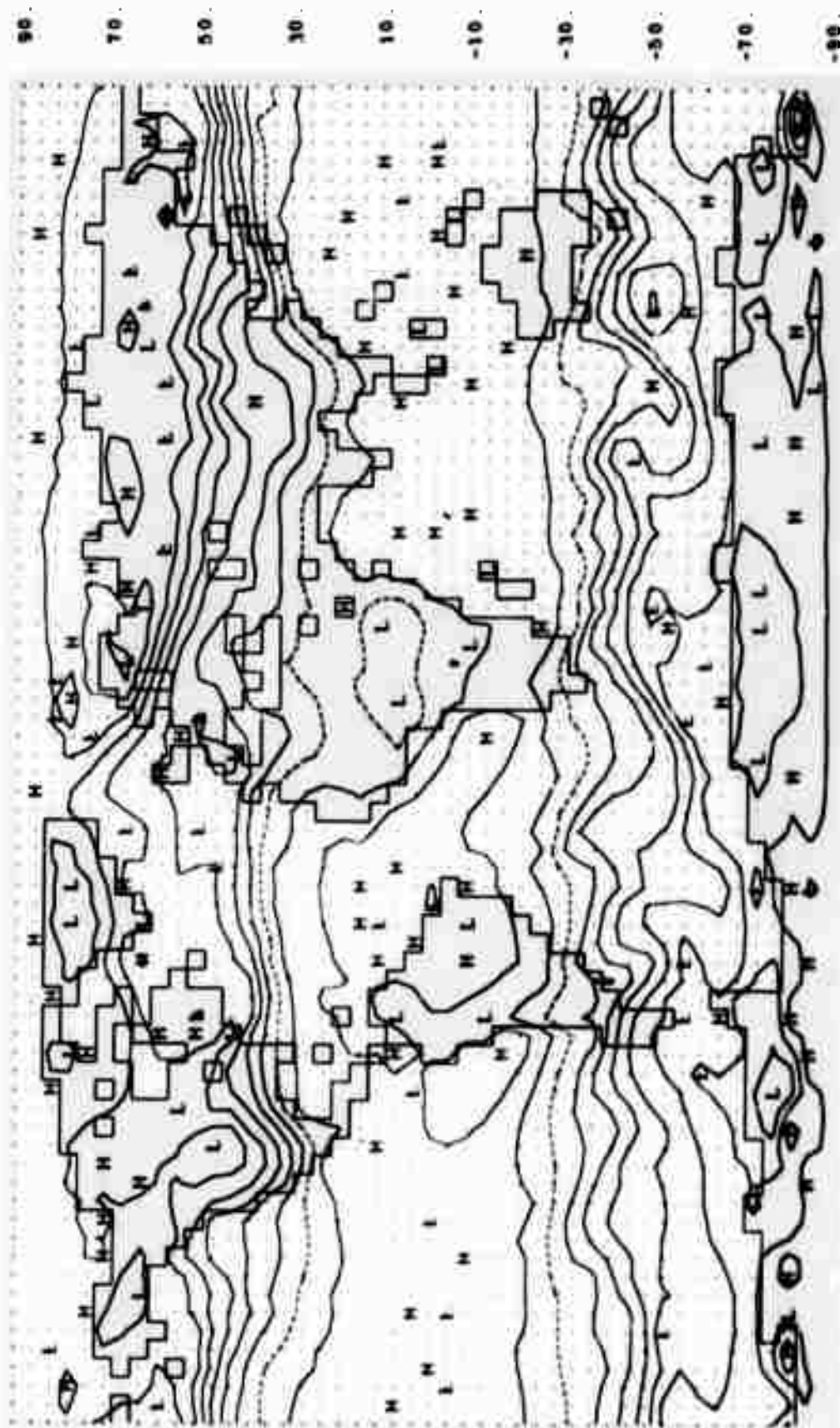


Fig. 6.6 -- Temperature at  $z = 1/4$ . The dashed line is  $-20^{\circ}\text{C}$  and the isoline interval is  $5^{\circ}\text{C}$ .

Fig. 4.7. Temperature (Map 4)

(deg C)

This map is calculated from the expression

$$T = \frac{(\sigma\pi + p_T)^\kappa}{p_3^\kappa - p_1^\kappa} \left\{ \frac{T_1}{p_1^\kappa} [p_3^\kappa - (\sigma\pi + p_T)^\kappa] \right. \\ \left. + \frac{T_3}{p_3^\kappa} [(\sigma\pi + p_T)^\kappa - p_1^\kappa] \right\} - 273.1 \text{ deg}$$

with  $0 \leq \sigma \leq 1$  an arbitrary  $\sigma$  surface. This represents the linear interpolation and extrapolation of the potential temperature  $\theta = T(p_0/p)^\kappa$  in  $p^\kappa$  space. For  $\sigma = 1/4$  and  $\sigma = 3/4$ , this reduces to the primary variables  $T_1$  and  $T_3$ , respectively. Here  $p_T$  is the tropopause pressure (= 200 mb), and  $\kappa = 0.286$ . The temperature may also be obtained at an arbitrary pressure surface  $p_T \leq p \leq p_S = \pi + p_T$  by replacing  $(\sigma\pi + p_T)$  in the above expression by  $p$ .

Level shown in map at right:  $\sigma = 3/4$ .

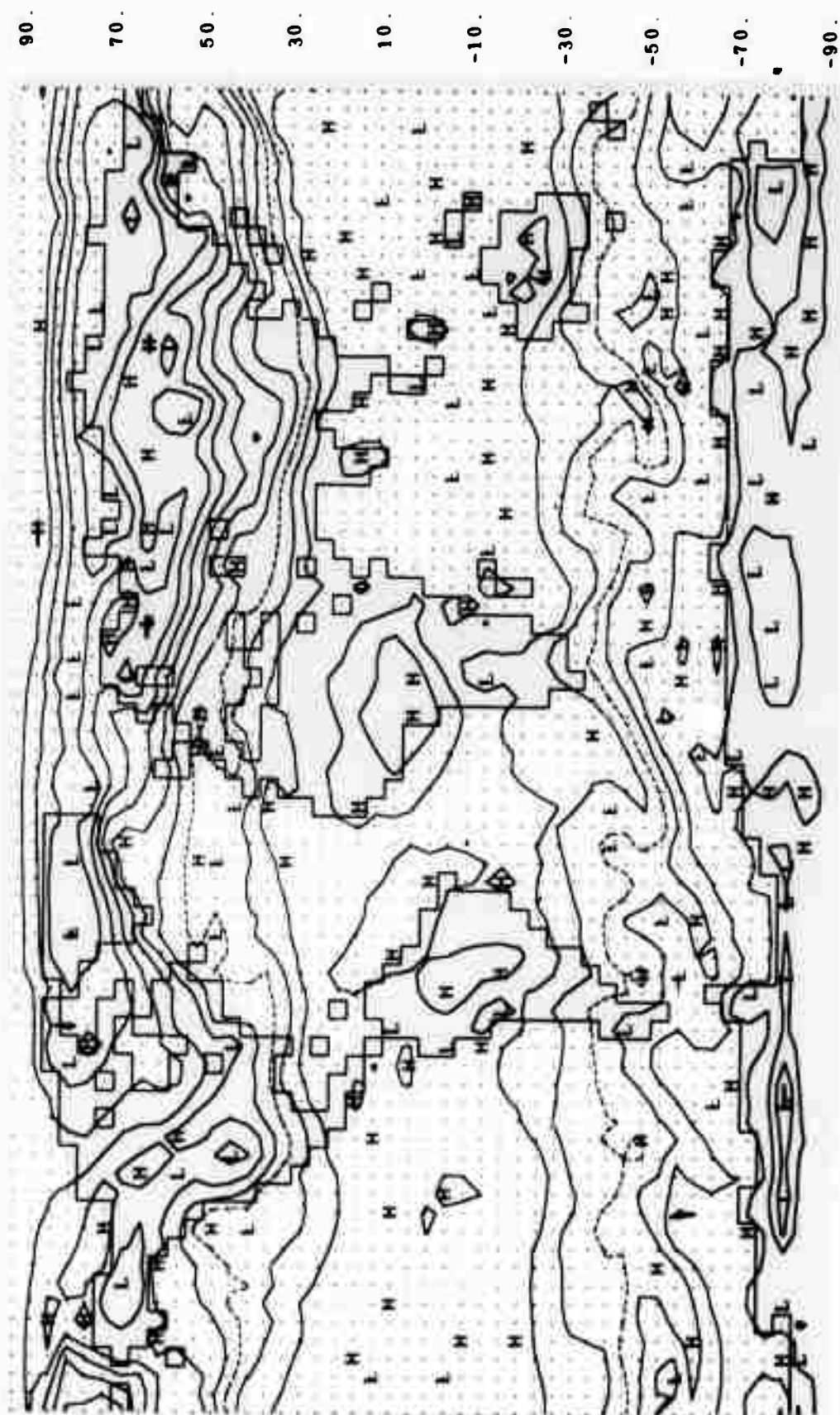


Fig. 4.7 -- Temperature at  $\tau = 3/4$ . The dashed line is  $0^{\circ}\text{C}$  and the isoline interval is  $5^{\circ}\text{C}$ .

Fig. 4.8. Geopotential Height of  $\sigma$  Surface (Map 6)

(100 m)

This map is calculated from the expression

$$z = \frac{\phi + \phi_4}{10^2 g}$$

where  $\phi_4$  is the geopotential of the earth's surface,  $g$  is the acceleration of gravity, and where the geopotential  $\phi$  of an arbitrary  $\sigma$  surface is given by

$$\phi = \frac{R}{2} \left\{ T_1 \left[ \frac{p_1 - p_T}{p_1} + \frac{p_3^{2\kappa} - p_1^{2\kappa} + 2p_1^\kappa p_3^\kappa - 4(\sigma\pi + p_T)^\kappa p_3^\kappa + 2(\sigma\pi + p_T)^{2\kappa}}{2\kappa p_1^\kappa (p_3^\kappa - p_1^\kappa)} \right] \right. \\ \left. + T_3 \left[ \frac{p_3 - p_T}{p_3} + \frac{p_3^{2\kappa} - p_1^{2\kappa} - 2p_1^\kappa p_3^\kappa + 4(\sigma\pi + p_T)^\kappa p_1^\kappa - 2(\sigma\pi + p_T)^{2\kappa}}{2\kappa p_3^\kappa (p_3^\kappa - p_1^\kappa)} \right] \right\}$$

Here  $p_T$  is the tropopause pressure ( $= 200$  mb),  $\kappa = 0.286$ , and  $R$  is the dry-air gas constant. For  $\sigma = 1/4$  and  $\sigma = 3/4$ , this reduces to  $\phi_1$  and  $\phi_3$ , respectively, while for other  $\sigma$  it represents a linear interpolation and extrapolation of the potential temperature in  $p^\kappa$  space. The geopotential height of an arbitrary pressure surface  $p_T \leq p \leq \pi + p_T$  may also be obtained by replacing  $(\sigma\pi + p_T)$  in the above expression by  $p$  (see Figs. 4.8a and 4.9a).

Level shown in map at right:  $\sigma = 1/4$ .



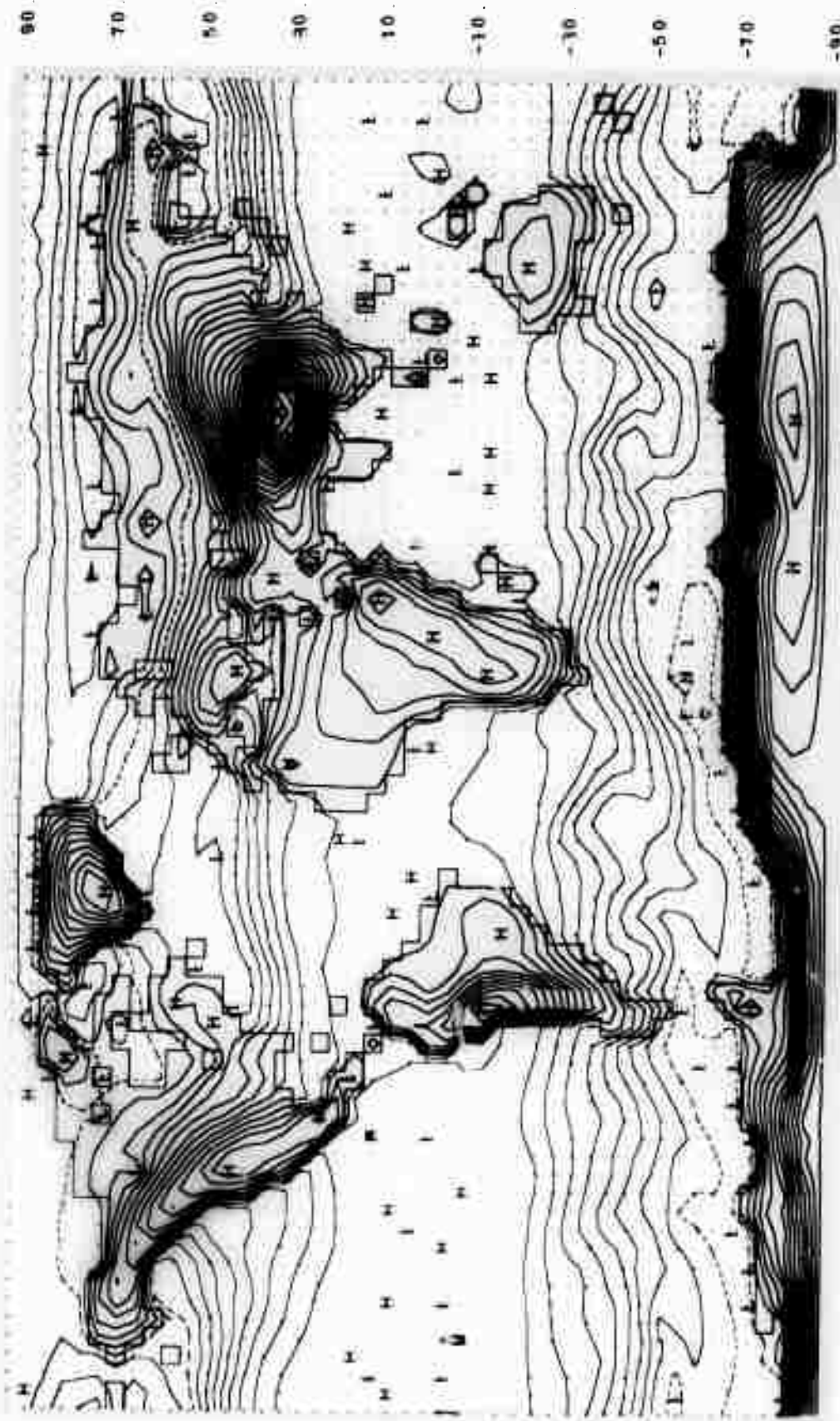


Fig. 4.8 -- Geopotential height at  $\sigma = 1/4$ . The dashed line is 7000 m and the isoline interval is 100 m.

Fig. 4.8a. Geopotential Height of Pressure Surface (Map 6)

(100 m)

This map is calculated from the expression

$$z = \frac{\phi + \phi_4}{10^2 g}$$

where  $\phi_4$  is the geopotential of the earth's surface,  $g$  is the acceleration of gravity, and where the geopotential  $\phi$  of an arbitrary  $p$  surface is given by

$$\phi = \frac{R}{2} \left\{ T_1 \left[ \frac{p_1 - p_T}{p_1} + \frac{p_3^{2\kappa} - p_1^{2\kappa} + 2p_1^\kappa p_3^\kappa - 4p_1^\kappa p_3^\kappa + 2p_3^{2\kappa}}{2\kappa p_1^\kappa (p_3^\kappa - p_1^\kappa)} \right] \right. \\ \left. + T_3 \left[ \frac{p_3 - p_T}{p_3} + \frac{p_3^{2\kappa} - p_1^{2\kappa} - 2p_1^\kappa p_3^\kappa + 4p_1^\kappa p_3^\kappa - 2p_1^{2\kappa}}{2\kappa p_3^\kappa (p_3^\kappa - p_1^\kappa)} \right] \right\}$$

Here  $p_T$  is the tropopause pressure (= 200 mb),  $\kappa = 0.286$ , and  $R$  is the dry-air gas constant. For  $p = p_1$  and  $p = p_3$ , this reduces to the height of the 400-mb and 800-mb surfaces, respectively, while for other  $p$  it represents a linear interpolation and extrapolation of the potential temperature in  $p^\kappa$  space. The geopotential height of an arbitrary  $\sigma$  surface  $0 \leq \sigma \leq 1$  may also be obtained by replacing  $p$  in the above expression by  $(\sigma\pi + p_T)$  (see Figs. 4.8 and 4.9).

Level shown in map at right:  $p = 400$  mb.

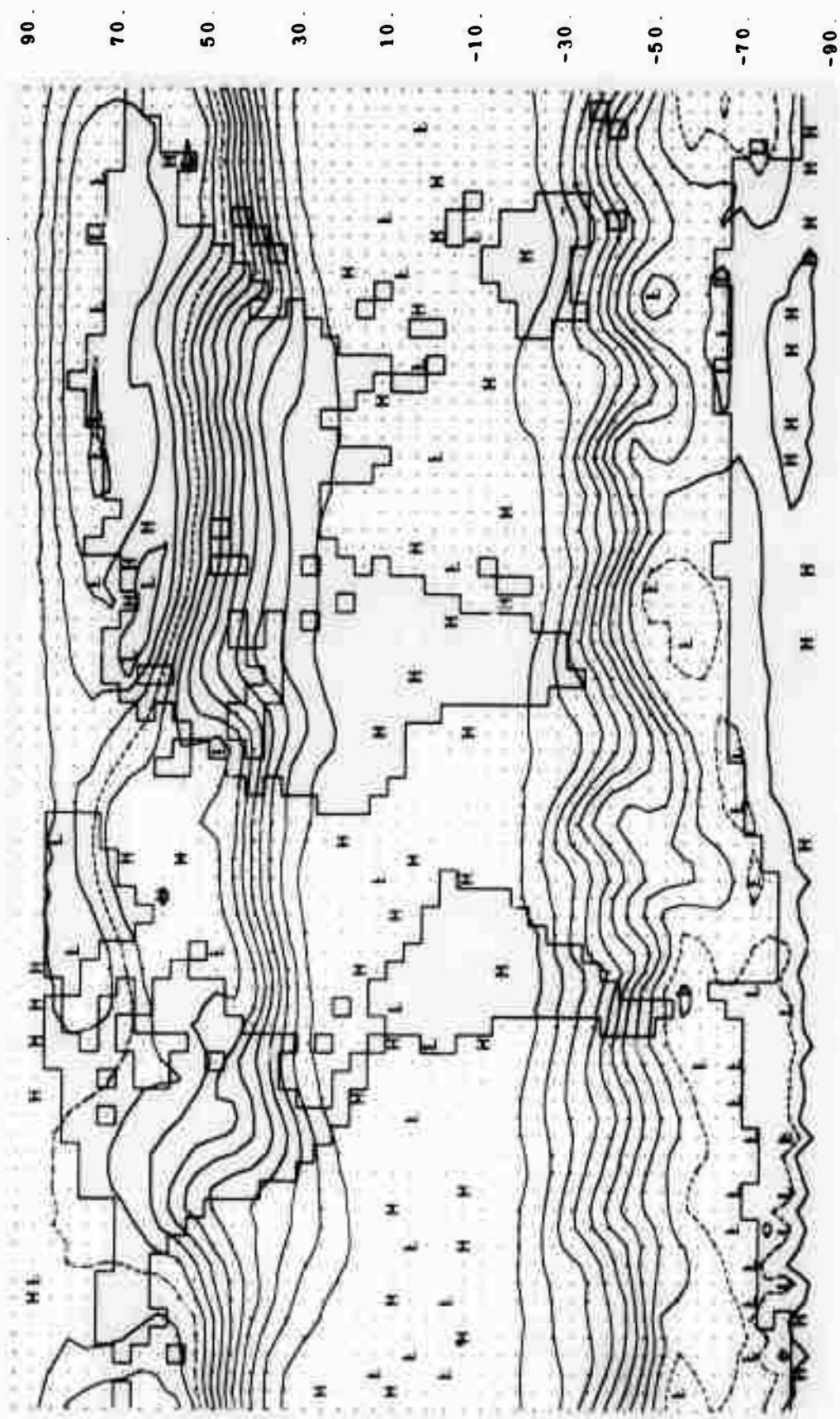


Fig. 4.8a -- Geopotential height at  $p = 400$  mb. The dashed line is 7000 m and the isoline interval is 100 m.

Fig. 9. Geopotential Height of  $\sigma$  Surface (Map 6)

(100 m)

This map is calculated from the expression

$$z = \frac{\phi + \phi_4}{10^2 g}$$

where  $\phi_4$  is the geopotential of the earth's surface,  $g$  is the acceleration of gravity, and where the geopotential  $\phi$  of an arbitrary  $\sigma$  surface is given by

$$\phi = \frac{R}{2} \left\{ T_1 \left[ \frac{p_1 - p_T}{p_1} + \frac{p_3^{2\kappa} - p_1^{2\kappa} + 2p_1^\kappa p_3^\kappa - 4(\sigma\pi + p_T)^\kappa p_3^\kappa + 2(\sigma\pi + p_T)^{2\kappa}}{2\kappa p_1^\kappa (p_3^\kappa - p_1^\kappa)} \right] \right. \\ \left. + T_3 \left[ \frac{p_3 - p_T}{p_3} + \frac{p_3^{2\kappa} - p_1^{2\kappa} - 2p_1^\kappa p_3^\kappa + 4(\sigma\pi + p_T)^\kappa p_1^\kappa - 2(\sigma\pi + p_T)^{2\kappa}}{2\kappa p_3^\kappa (p_3^\kappa - p_1^\kappa)} \right] \right\}$$

Here  $p_T$  is the tropopause pressure (= 200 mb),  $\kappa = 0.286$ , and  $R$  is the dry-air gas constant. For  $\sigma = 1/4$  and  $\sigma = 3/4$ , this reduces to  $\phi_1$  and  $\phi_3$ , respectively, while for other  $\sigma$  it represents a linear interpolation and extrapolation of the potential temperature in  $p^\kappa$  space.

The geopotential height of an arbitrary pressure surface  $p_T \leq p \leq \pi + p_T$  may also be obtained by replacing  $(\sigma\pi + p_T)$  in the above expression by  $p$  (see Figs. 4.8a and 4.9a).

Level shown in map at right:  $\sigma = 3/4$ .

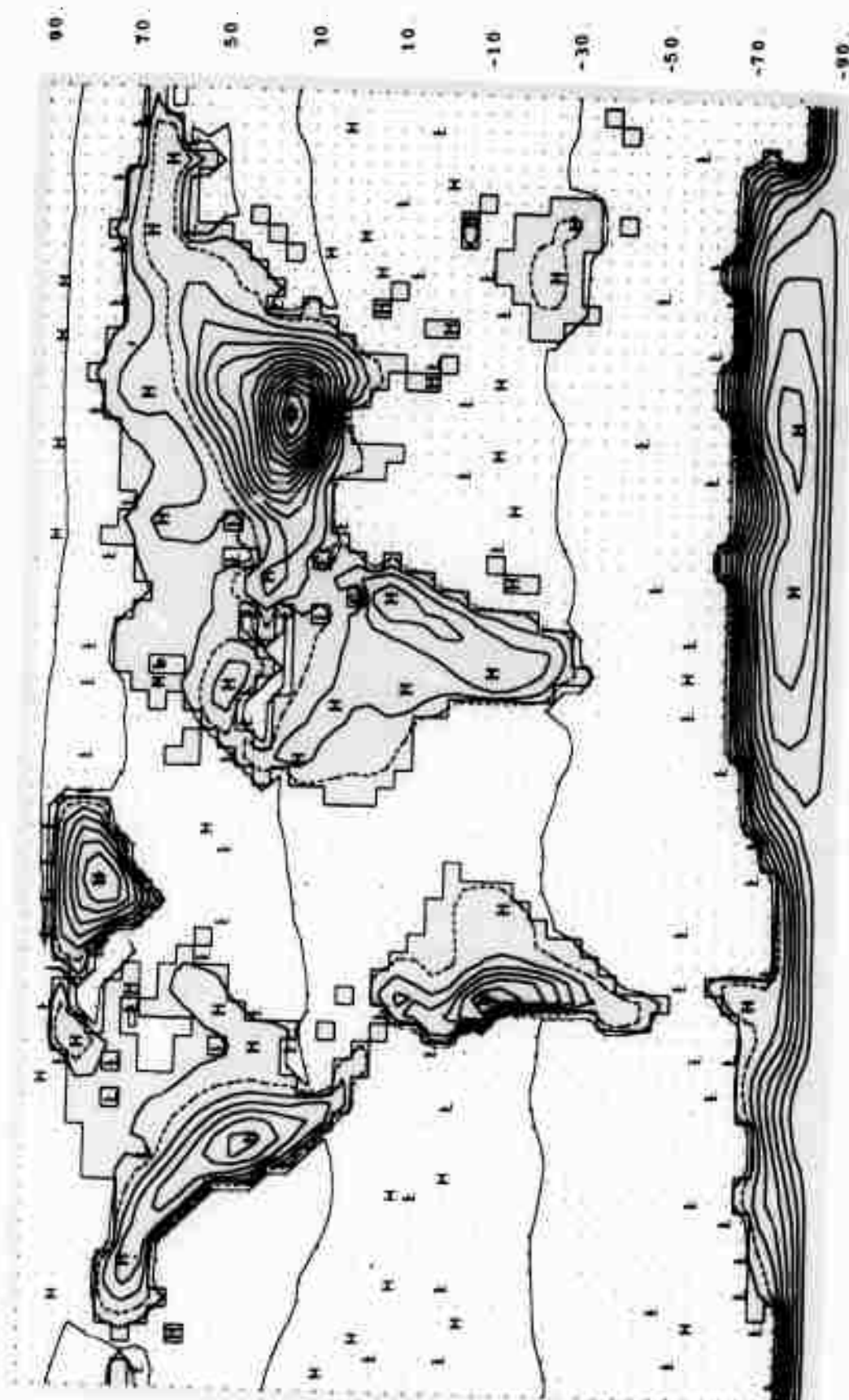


Fig. 4.9 -- Geopotential height at  $\sigma = 3/4$ . The dashed line is 2500 m and the isoline interval is 250 m.

Fig. 4.9a. Geopotential Height of Pressure Surface (Map 6)

(100 m)

This map is calculated from the expression

$$z = \frac{\phi + \phi_4}{10^2 g}$$

where  $\phi_4$  is the geopotential of the earth's surface,  $g$  is the acceleration of gravity, and where the geopotential  $\phi$  of an arbitrary  $p$  surface is given by

$$\phi = \frac{R}{2} \left\{ T_1 \left[ \frac{p_1 - p_T}{p_1} + \frac{p_3^{2\kappa} - p_1^{2\kappa} + 2p_1^\kappa p_3^\kappa - 4p_1^\kappa p_3^\kappa + 2p_1^{2\kappa}}{2\kappa p_1^\kappa (p_3^\kappa - p_1^\kappa)} \right] \right. \\ \left. + T_3 \left[ \frac{p_3 - p_T}{p_3} + \frac{p_3^{2\kappa} - p_1^{2\kappa} - 2p_1^\kappa p_3^\kappa + 4p_1^\kappa p_3^\kappa - 2p_1^{2\kappa}}{2\kappa p_3^\kappa (p_3^\kappa - p_1^\kappa)} \right] \right\}$$

Here  $p_T$  is the tropopause pressure (= 200 mb),  $\kappa = 0.286$ , and  $R$  is the dry-air gas constant. For  $p = p_1$  and  $p = p_3$ , this reduces to the height of the 400-mb and 800-mb surfaces, respectively, while for other  $p$  it represents a linear interpolation and extrapolation of the potential temperature in  $p^\kappa$  space. The geopotential height of an arbitrary  $\sigma$  surface  $0 \leq \sigma \leq 1$  may also be obtained by replacing  $p$  in the above expression by  $(\sigma\pi + p_T)$  (see Figs. 4.8 and 4.9).

Level shown in map at right:  $p = 800$  mb.

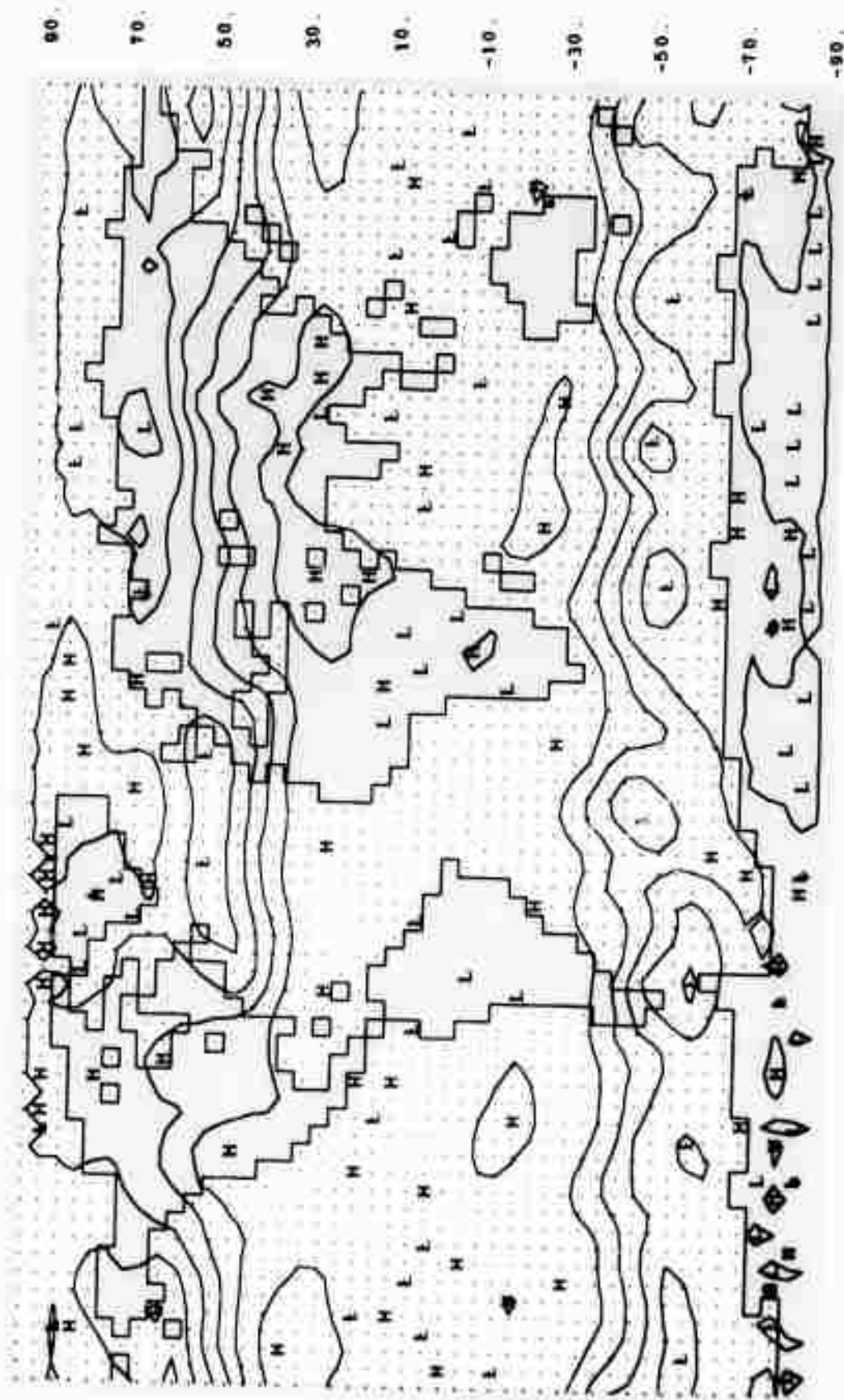


Fig. 4.9.1 -- Geopotential height at  $p = 800$  mb. The dashed line is 2300 m and the isoline interval is 100 m.

Fig. 4.10. Total Heating (Map 8)  
(deg day<sup>-1</sup>)

This map is calculated from the expression

$$H = 2 \left[ H_1 \left( \frac{3}{4} - \sigma \right) + H_3 \left( \sigma - \frac{1}{4} \right) \right] 48$$

where  $H_1$  and  $H_3$  are the net temperature changes in the upper and lower layers, respectively, over a time interval  $5\Delta t$  (the time interval over which the heating is calculated by means of the subroutine COMP 3). Here

$$H_1 = (\Delta T_1)_{CM} + (\Delta T_1)_{CP} + \left( \frac{A_1 + R_2 - R_0}{c_p} \frac{2g}{\pi} \frac{1}{48} \right)$$

$$H_3 = (\Delta T_3)_{CM} + (\Delta T_3)_{CP} + \frac{L}{c_p} \text{PREC} + \left( \frac{A_3 + R_4 - R_2 + F_4}{c_p} - \frac{2g}{\pi} \frac{1}{48} \right)$$

where  $(\Delta T_1)_{CM}$  and  $(\Delta T_1)_{CP}$  are the temperature changes (over  $5\Delta t$ ) due to middle-level and penetrating convective heating in the upper layer, respectively [with  $(\Delta T_3)_{CM}$  and  $(\Delta T_3)_{CP}$  similarly defined for the lower layer],  $A_1$  and  $A_3$  are the net rates of short-wave radiant-energy absorption in the two layers,  $R_0$ ,  $R_2$ , and  $R_4$  are the upward long-wave radiative flux at each level,  $F_4$  is the upward flux of sensible heat from the surface,  $L$  is the latent heat of condensation, and PREC is the large-scale condensation or precipitation rate. The factor  $(2g/\pi)^{-1}$  represents the mass in each layer (per unit area), and the factor 48 (the number of times in a day the heating is calculated) converts to the desired units (see Chapter II, Sections F and G, and instructions 11410 to 11490, COMP 3, for further details).

For  $\sigma = 1/4$  and  $\sigma = 3/4$ , this expression reduces to the net heat-induced temperature changes in the upper and lower layers,  $H_1$  and  $H_3$ , respectively. For other  $0 \leq \sigma \leq 1$  it represents the assignment of the layer's temperature change to its midpoint, and the subsequent linear interpolation and extrapolation in  $\sigma$  (or  $p$ ) space. This representation of the diabatic heating may also be generated for an arbitrary pressure,  $p$ , by replacing  $\sigma$  in the above expression by  $(p - p_T)/\pi$ .

Level shown in map at right:  $\sigma = 1/4$ .



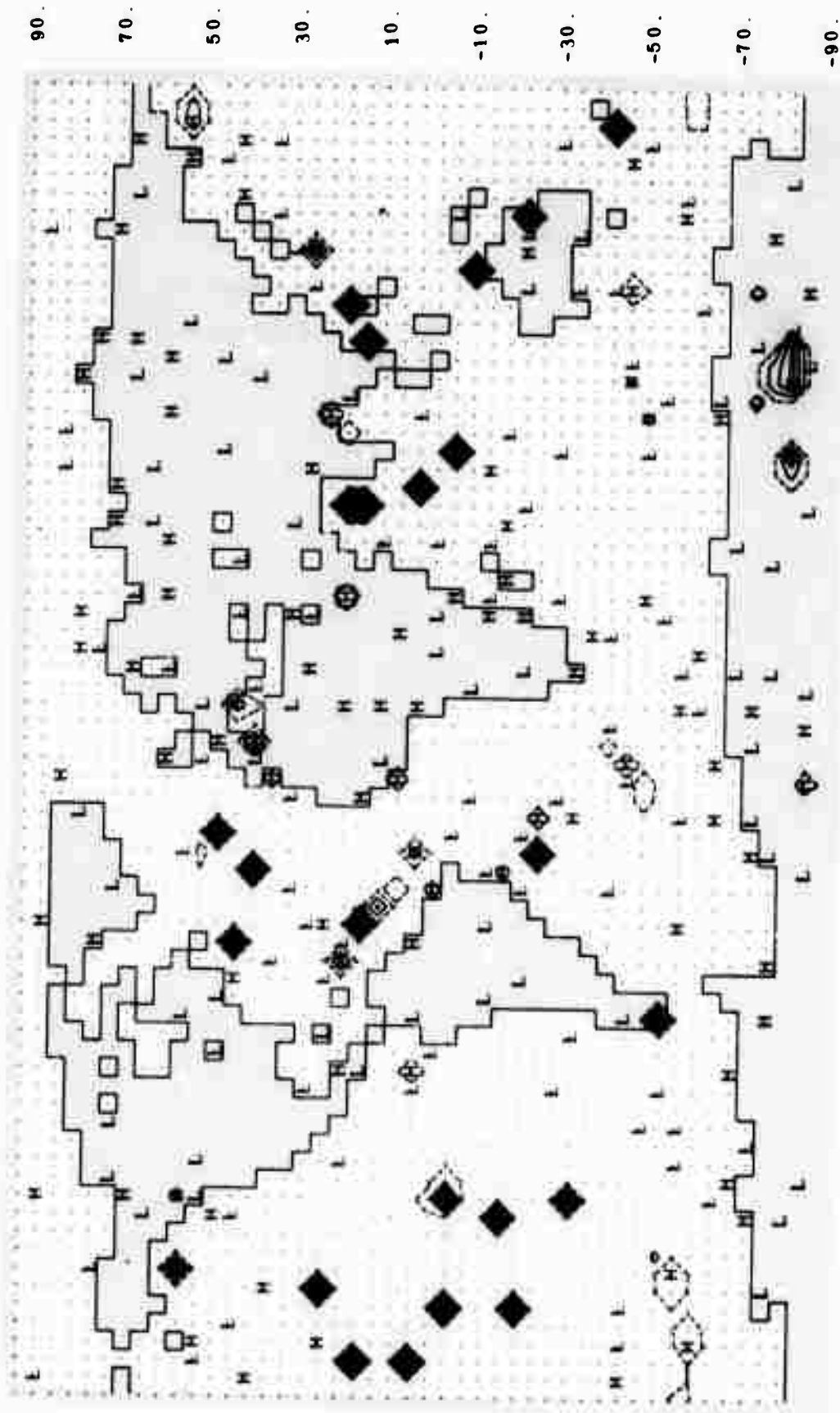


Fig. 4.10 -- Total diabatic heating rate at  $\tau = 1/4$ . The dashed line is 0 and the isoline interval is 5 deg day<sup>-1</sup>.

Fig. 4.11. Total Heating (Map 8)  
(deg day<sup>-1</sup>)

This map is calculated from the expression

$$H = 2 \left[ H_1 \left( \frac{3}{4} - \sigma \right) + H_3 \left( \sigma - \frac{1}{4} \right) \right] 48$$

where  $H_1$  and  $H_3$  are the net temperature changes in the upper and lower layers, respectively, over a time interval  $5\Delta t$  (the time interval over which the heating is calculated by means of the subroutine COMP 3). Here

$$H_1 = (\Delta T_1)_{CM} + (\Delta T_1)_{CP} + \left( \frac{A_1 + R_2 - R_0}{c_p} \frac{2g}{\pi} \frac{1}{48} \right)$$

$$H_3 = (\Delta T_3)_{CM} + (\Delta T_3)_{CP} + \frac{L}{c_p} \text{PREC} + \left( \frac{A_3 + R_4 - R_2 + F_4}{c_p} \frac{2g}{\pi} \frac{1}{48} \right)$$

where  $(\Delta T_1)_{CM}$  and  $(\Delta T_1)_{CP}$  are the temperature changes (over  $5\Delta t$ ) due to middle-level and penetrating convective heating in the upper layer, respectively [with  $(\Delta T_3)_{CM}$  and  $(\Delta T_3)_{CP}$  similarly defined for the lower layer],  $A_1$  and  $A_3$  are the net rates of short-wave radiant-energy absorption in the two layers,  $R_0$ ,  $R_2$ , and  $R_4$  are the upward long-wave radiative flux at each level,  $F_4$  is the upward flux of sensible heat from the surface,  $L$  is the latent heat of condensation, and PREC is the large-scale condensation or precipitation rate. The factor  $(2g/\pi)^{-1}$  represents the mass in each layer (per unit area), and the factor 48 (the number of times in a day the heating is calculated) converts to the desired units (see Chapter II, Sections F and G, and instructions 11410 to 11490, COMP 3, for further details).

For  $\sigma = 1/4$  and  $\sigma = 3/4$ , this expression reduces to the net heat-induced temperature changes in the upper and lower layers,  $H_1$  and  $H_3$ , respectively. For other  $0 \leq \sigma \leq 1$  it represents the assignment of the layer's temperature change to its midpoint, and the subsequent linear interpolation and extrapolation in  $\sigma$  (or  $p$ ) space. This representation of the diabatic heating may also be generated for an arbitrary pressure,  $p$ , by replacing  $\sigma$  in the above expression by  $(p - p_T)/\pi$ .

Level shown in map at right:  $\sigma = 3/4$ .

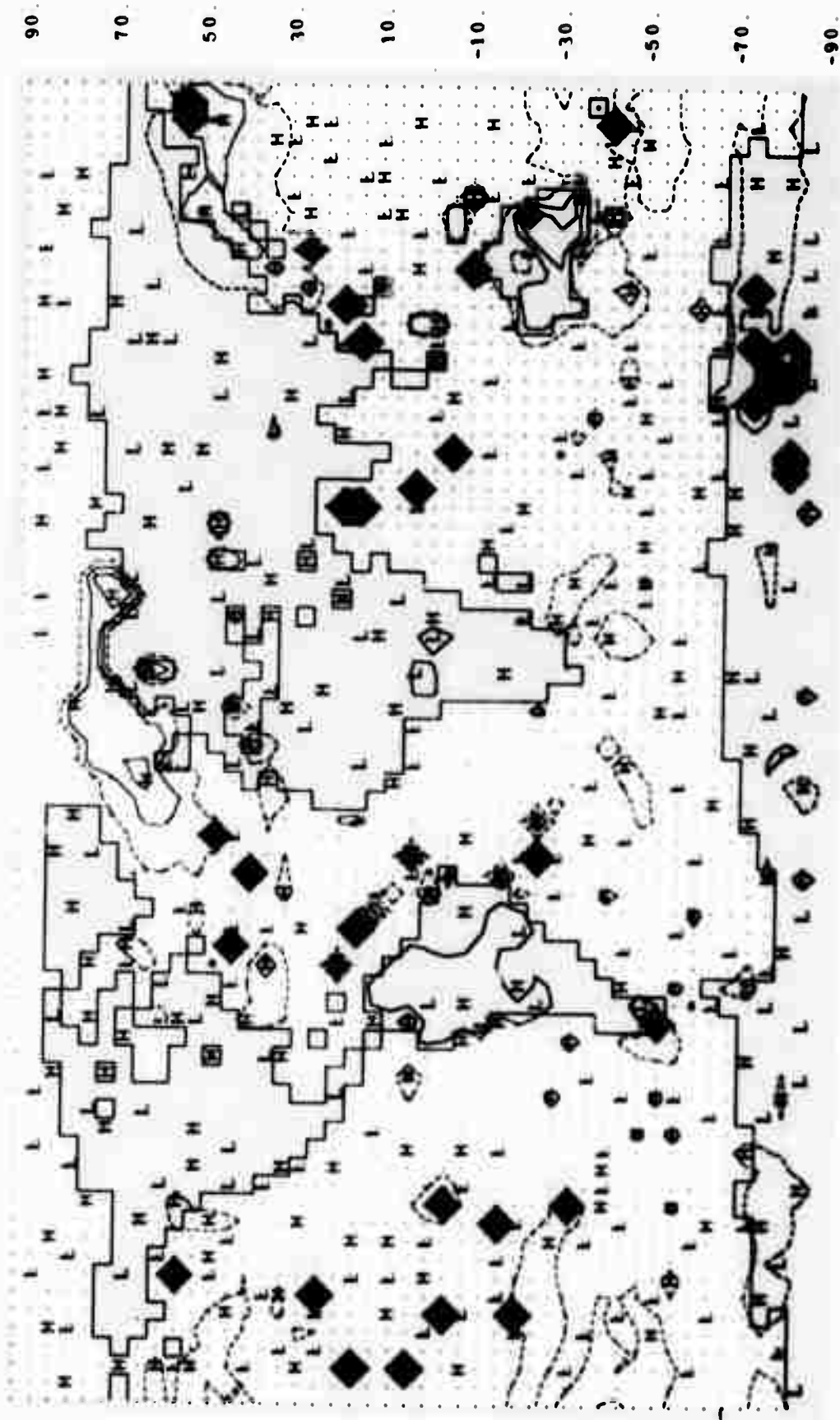


Fig. 4.11 -- Total diabatic heating rate at  $\tau = 3/4$ . The dashed line is 0 and the isoline interval is 5 deg day<sup>-1</sup>.

Fig. 4.12. Large-Scale Precipitation Rate (Map 9)

(mm day<sup>-1</sup>)

This map is calculated from the expression

$$\text{PREC} \left( \frac{\pi}{2g} \right) 48 \frac{10^2}{\rho_w}$$

where the large-scale precipitation rate (PREC) is taken equal to the rate of generation of water vapor in excess of saturation (i.e., the condensation rate) in the lower layer, and is given by

$$\text{PREC} = \begin{cases} [q_3 - q_s(T_3)](1 + \gamma_3)^{-1}, & q_3 > q_s(T_3) \\ 0 & , \text{ otherwise} \end{cases}$$

where  $q_3$  is the water-vapor mixing ratio at level 3,  $q_s(T_3)$  is the saturated mixing ratio at the ambient level-3 temperature  $T_3$  (see Fig. 4.14), and the parameter  $\gamma_3 = Lq_s(T_3)(c_p T_3^2)^{-1} 5418 \text{ deg}$ , with  $L$  the latent heat of condensation and  $c_p$  the dry-air specific heat at constant pressure. The factor  $\pi/2g$  represents the mass (per unit area) in the lower-layer air column ( $\sigma = 1$  to  $\sigma = 1/2$ ). The factor 48 (the ratio of 1 day to 5Δt) represents the number of times per day the precipitation (PREC) is computed by means of the subroutine COMP 3. Together with the density of water,  $\rho_w = 1 \text{ g cm}^{-3}$ , the factor  $10^2$  converts to the desired units. See Chapter II, Section F and instructions 8610 to 8690, COMP 3, for further details.

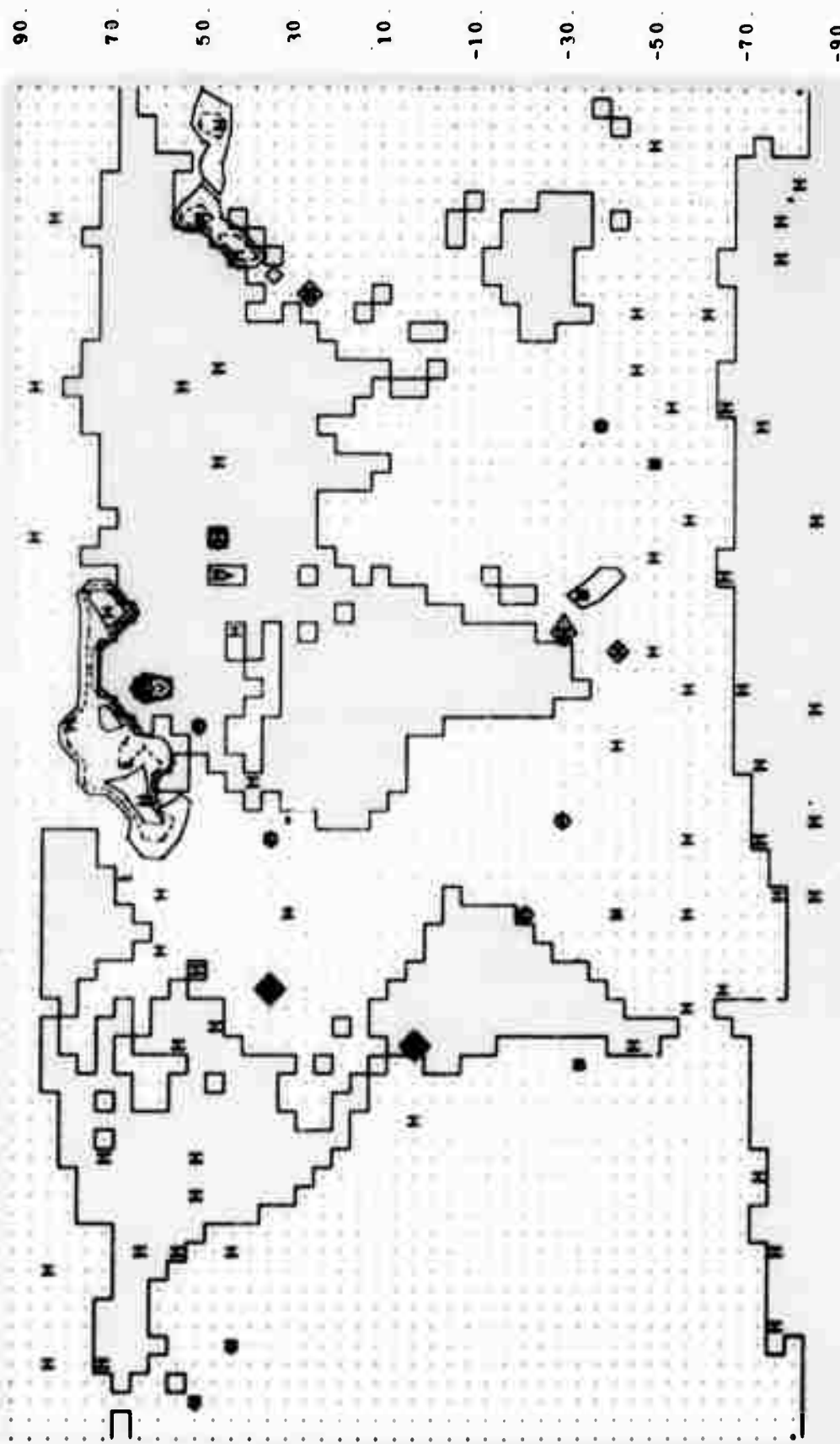


Fig. 4.12 -- Large-scale precipitation rate. The dashed line is 4 mm day<sup>-1</sup> and the isohal interval is 2 mm day<sup>-1</sup>.

Fig. 4.13. Sigma Vertical Velocity (Map 10)

(mb hr<sup>-1</sup>)

This map is calculated from the expression

$$\pi \dot{\sigma} = \frac{\dot{S}}{2mn}$$

where  $\dot{\sigma} = \dot{\sigma}_2 = d\sigma/dt$  at level 2 and  $\dot{S}$  is a measure of the difference in horizontal mass convergence between levels 1 and 3, given by Eq. (2.34), Chapter II, as

$$\dot{S} = \frac{1}{2} \left[ \left( \frac{\partial u_3^*}{\partial x} + \frac{\partial v_3^*}{\partial y} \right) - \left( \frac{\partial u_1^*}{\partial x} + \frac{\partial v_1^*}{\partial y} \right) \right]$$

where  $u^* = n\pi u$  and  $v^* = m\pi v$  are weighted mass fluxes at the levels 1 or 3, and  $n$  and  $m$  are the meridional distance ( $y$ ) and zonal distance ( $x$ ) between  $u, v$  grid points. The sigma vertical velocity may also be written  $\pi \dot{\sigma} = \omega - \sigma \dot{\pi}$ , where  $\omega = dp/dt$  is the isobaric vertical velocity and  $\dot{\pi} = dp_s/dt$ , with  $p_s$  the surface pressure. See Chapter II for further details of  $\dot{S}$ , representing an integration of the equation of continuity. See instructions 4130 to 4550, COMP 1, for further details.

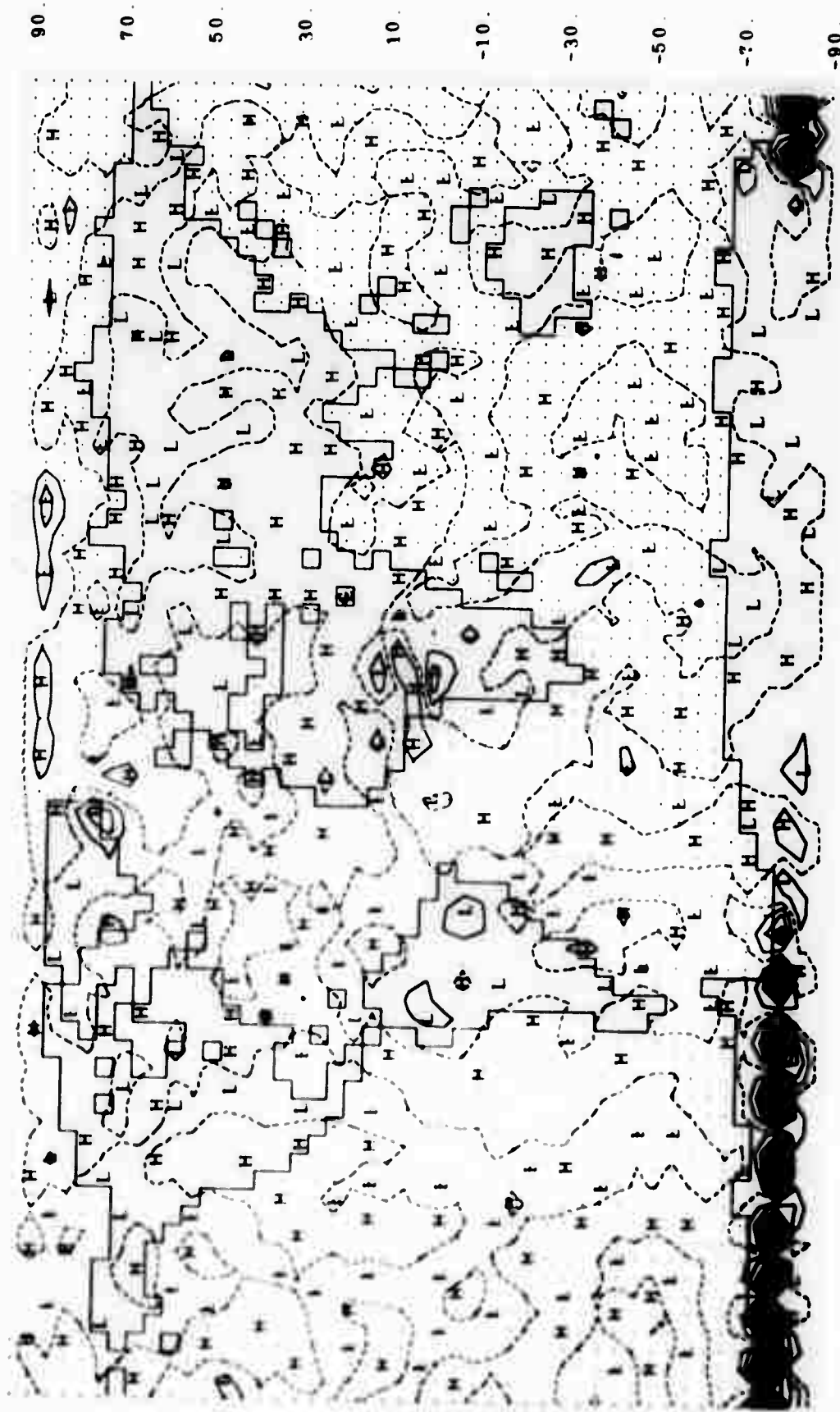


Fig. 4.13 -- Sigma vertical velocity. The dashed line is 0 and the isoline interval is 10 mb hr<sup>-1</sup>.

Fig. 4.14. Relative Humidity (Map 11)  
(percent)

This map is calculated from the expression

$$q_3 \cdot 10^2 / q_s(T_3)$$

where  $q_3$  is the water-vapor mixing ratio at level 3 and  $q_s(T_3)$  is the saturation mixing ratio at the ambient level-3 air temperature  $T_3$ . Here  $q_s(T_3)$  is given by

$$q_s(T_3) = \frac{0.622 e_s(T_3)}{0.1p_3 - e_s(T_3)}$$

where  $p_3$  is the (total) pressure at level 3, and the saturation vapor pressure  $e_s(T_3)$  is given by the semi-empirical formula

$$e_s(T_3) = 10 \exp(8.4051 - 2353 \text{ deg}/T_3)$$

Both  $p_3$  and  $e_s$  here are in the units cb (centibar =  $10^{-2}$  bar = 10 mb). These relationships permit a supersaturation of a few percent in very moist air.

All of the atmospheric humidity is carried in the model at level 3 (i.e.,  $q_1 \equiv 0$ ), so that Map 11 is always for the level  $\sigma = 3/4$ .



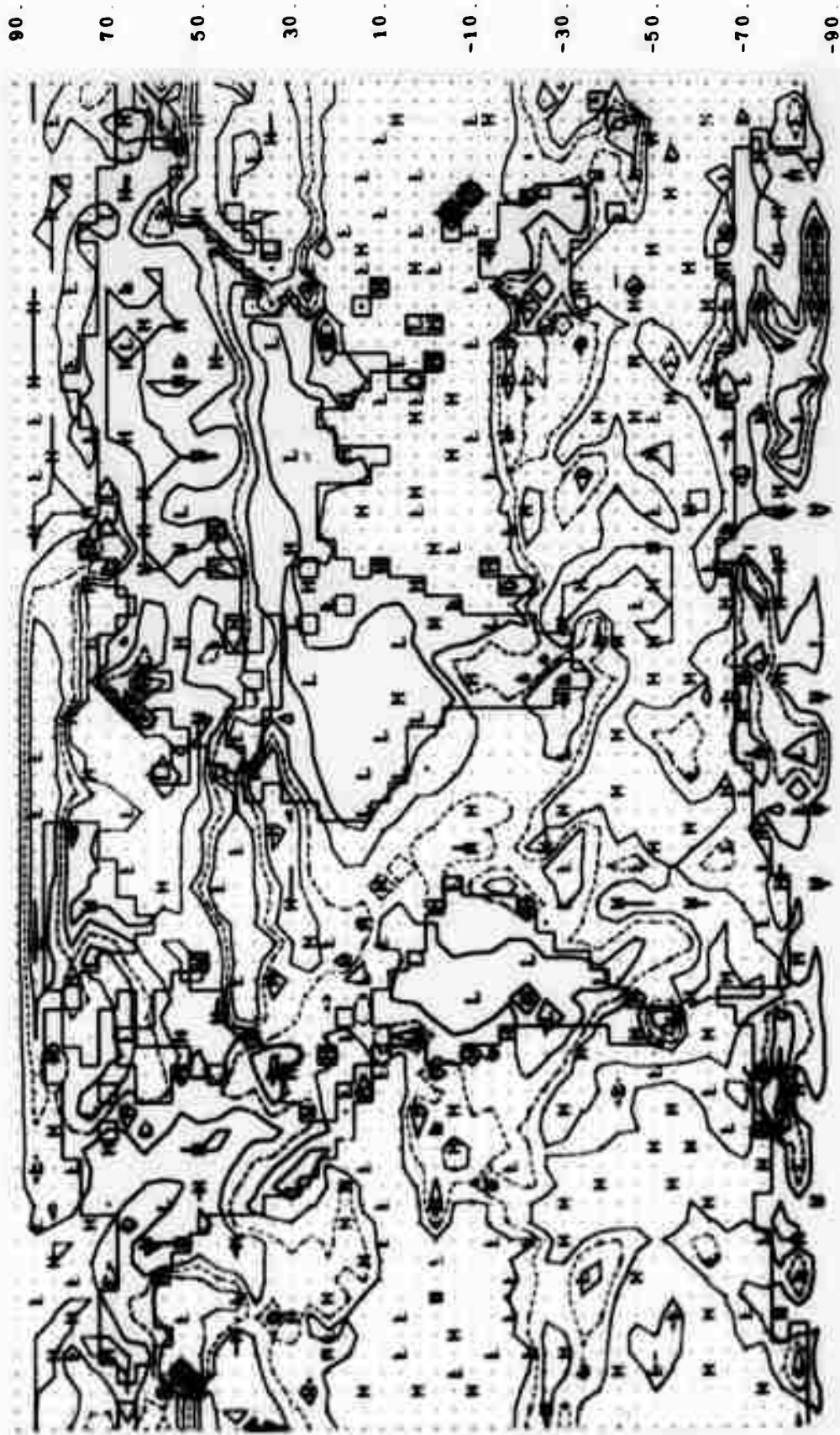


Fig. 1.1' -- Relative humidity at  $\sigma = 3/4$ . The dashed line is 60 percent and the isoline interval is 20 percent.

Fig. 4.15. Precipitable Water (Map 12)

(cm)

This map is calculated from the expression

$$q_3 \left( \frac{\pi}{2g} \right) \frac{10}{\rho_w}$$

where  $q_3$ , the mixing ratio at level 3, is interpreted as the average mixing ratio between the surface ( $\sigma = 1$ ) and level 2 ( $\sigma = 1/2$ ), and where the density of water,  $\rho_w$ , is taken as  $1 \text{ g cm}^{-3}$ , which together with the factor 10 serves to give the desired units. The factor  $\pi/2g$  represents the mass (per unit area) in the lower half of the air column ( $\sigma = 1$  to  $\sigma = 1/2$ ), and results from the vertical integration of the water-vapor distribution.

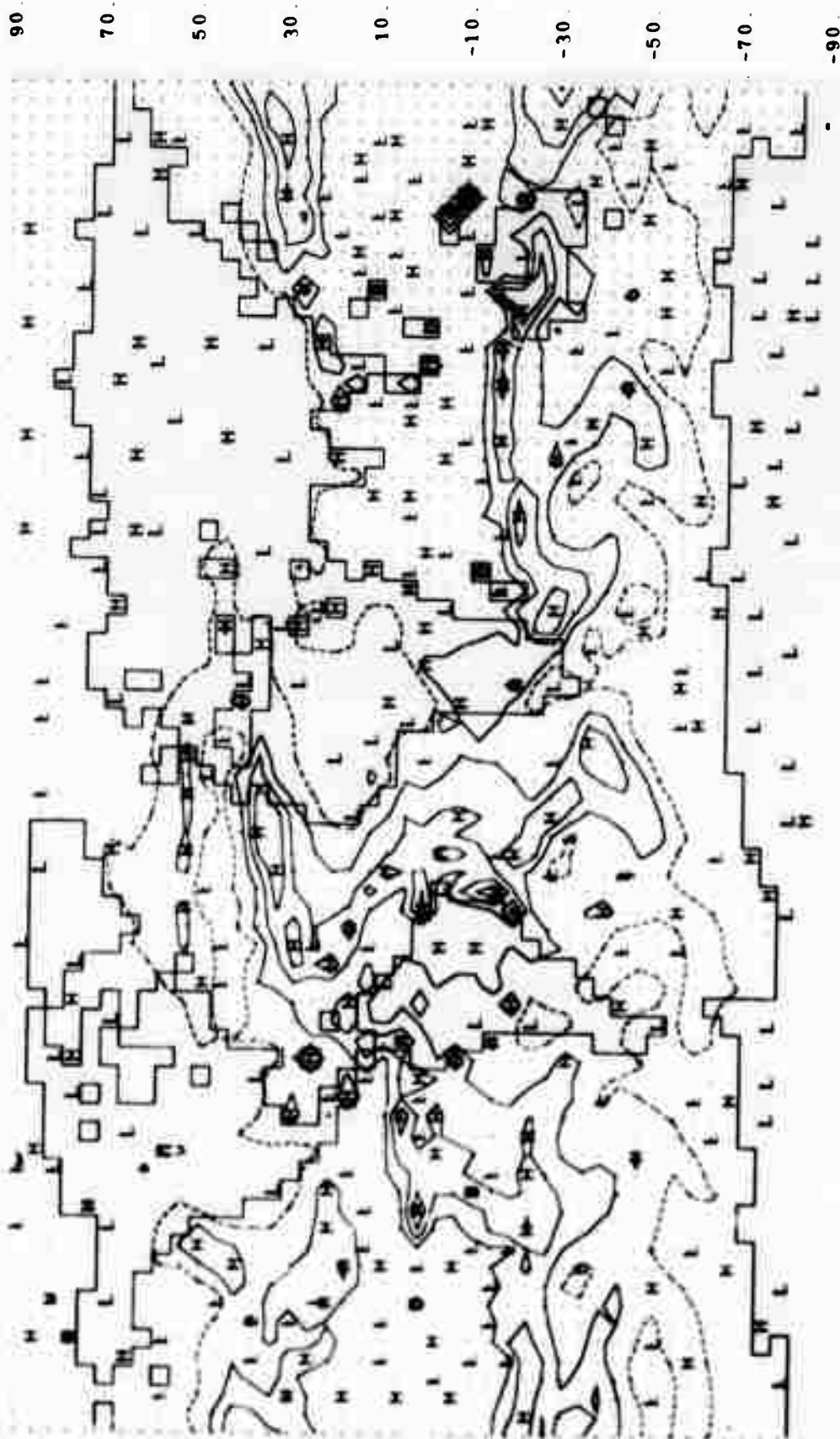


Fig. 4.13 -- Total precipitable water in column from  $\tau = 1$  to  $\tau = 1/2$ . The dashed line is 1 cm and the isohyline interval is 1 cm.

Fig. 4.16. Convective Precipitation Rate (Map 13)

(mm day<sup>-1</sup>)

This map is calculated from the expression

$$\frac{(\Delta T_1)_{CM} + (\Delta T_1)_{CP} + (\Delta T_3)_{CM} + (\Delta T_3)_{CP}}{L/c_p} \left(\frac{\pi}{2g}\right) 48 \frac{10^2}{\rho_w}$$

where  $(\Delta T_1)_{CM}$  and  $(\Delta T_1)_{CP}$  are the temperature changes (over  $5\Delta t$ ) due to middle-level and penetrating convective heat transport in the upper layer, respectively [with  $(\Delta T_3)_{CM}$  and  $(\Delta T_3)_{CP}$  similarly defined for the lower layer],  $L$  is the latent heat of condensation,  $c_p$  is the specific heat at constant pressure,  $\rho_w = 1 \text{ g cm}^{-3}$  is the density of water, the factor  $\pi/2g$  represents the mass in each layer (per unit area), and the factor 48 (the number of  $5\Delta t$  intervals in one day) together with the factor  $10^2$  serves to convert to the desired units. The quantity

$$\left[ (\Delta T_1)_{CM} + (\Delta T_1)_{CP} + (\Delta T_3)_{CM} + (\Delta T_3)_{CP} \right] (L/c_p)^{-1} = C1 + PC1 + C3 + PC3$$

in FORTRAN notation, and corresponds to the quantity PREC in Map 9 for the large-scale precipitation rate.

In the map shown on the right, the convective precipitation rate has a maximum of approximately 244 mm day<sup>-1</sup>. This rate, however, lasts for a relatively short time, and, due to the nature of the computed convective heating, characteristically occurs at isolated grid points. See instructions 8700 to 8890, 9140 to 9390, COMP 3, and Chapter II, Subsection F.3, for further details.

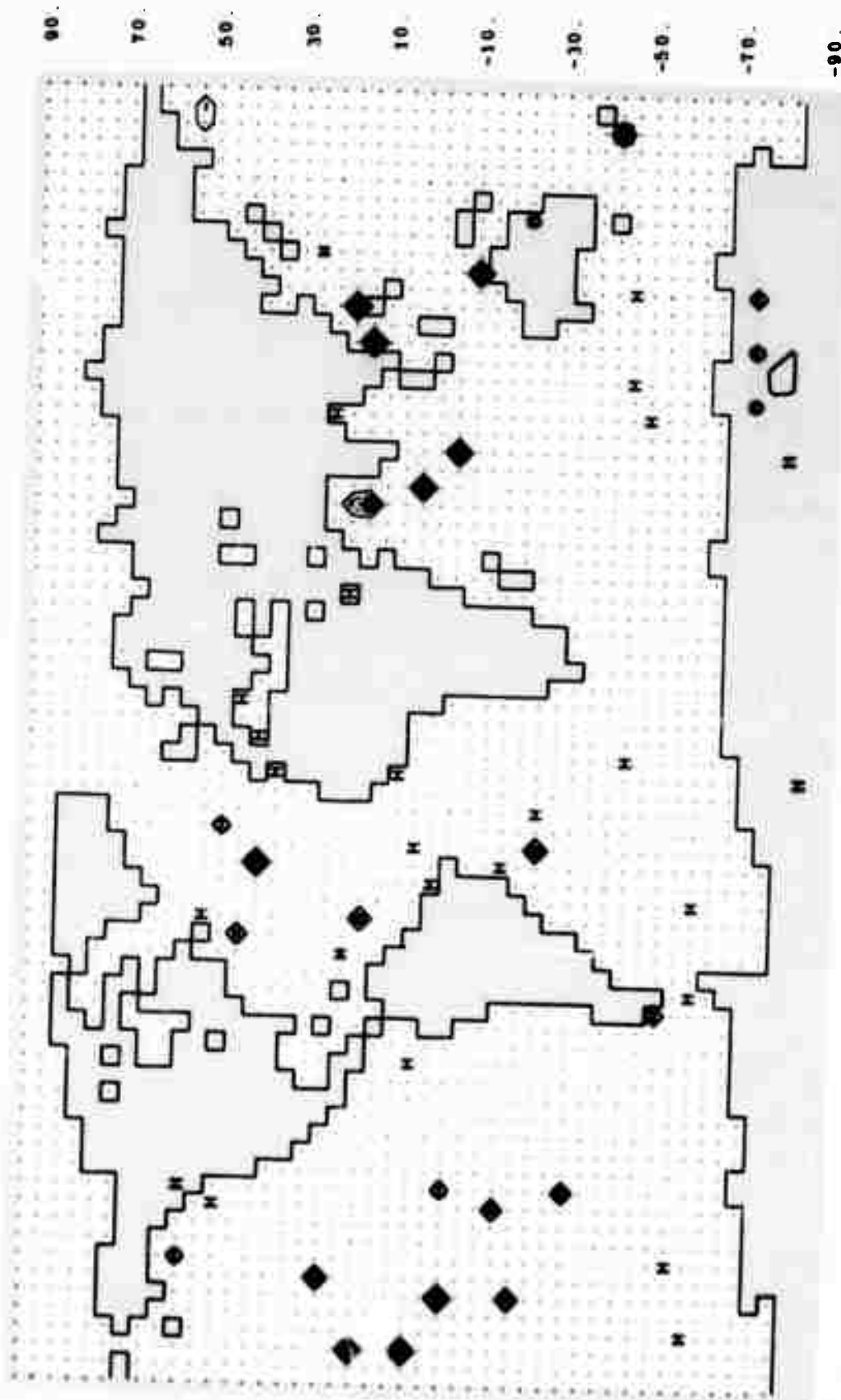


Fig. 6.16 -- Convective precipitation rate. The dashed line is 100 mm day<sup>-1</sup> and the isoline interval is 50 mm day<sup>-1</sup>.

Fig. 4.17. Evaporation Rate (Map 14)  
(mm day<sup>-1</sup>)

This map is calculated from the expression

$$\frac{E_4}{\rho_w} \cdot 10 \text{ DAY} = \frac{C_D \rho_4}{\rho_w} \left( |\vec{V}_s|_{00}^\pi + 2.0 \text{ m sec}^{-1} \right) \left[ \text{WET} \cdot q_s(T_g) + \text{WET} \cdot \frac{5418 \cdot \text{deg } q_s(T_g)}{T_g^2} (TGR - T_g) - Q_4 \right] 10^3 \text{ DAY}$$

where  $E_4$  is the evaporation in g cm<sup>-2</sup> sec<sup>-1</sup>,  $\rho_4$  is the surface air density,  $\rho_w = 1 \text{ g cm}^{-3}$  the density of water, WET a (calculated) ground wetness parameter,  $q_s(T_g)$  the saturated mixing ratio at the (computed) ground temperature  $T_g$ , TGR a (computed) ground temperature parameter including the effects of radiation, and  $Q_4$  a measure of the mixing ratio at level 4. The surface drag coefficient  $C_D$  is given by

$$C_D = \begin{cases} \min \left[ \left( 1.0 + 0.07 |\vec{V}_s|_{00}^\pi \right) 10^{-3}, 0.0025 \right], & \text{if ocean} \\ 0.002 + 0.006 (z_4/5000 \text{ m}) & , \text{ otherwise} \end{cases}$$

with  $z_4$  the elevation of the surface. Here  $|\vec{V}_s|_{00}^\pi$  is given in terms of the wind speeds at the four velocity points surrounding a pressure (or temperature) point by the expression (in  $\pi$ -centered notation)

$$|\vec{V}_s|_{00}^\pi = \frac{1}{2} \left[ |\vec{V}_s|_{11}^2 + |\vec{V}_s|_{-11}^2 + |\vec{V}_s|_{-1-1}^2 + |\vec{V}_s|_{1-1}^2 \right]^{1/2}$$

where  $\vec{V}_s = 0.7 |\vec{V}_4|$  and  $\vec{V}_4 = \frac{3}{2} \vec{V}_3 - \frac{1}{2} \vec{V}_1$  (the wind extrapolated to level 4). The additive term  $2.0 \text{ m sec}^{-1}$  is an empirical correction for gustiness, and the factors  $10$ ,  $10^3$ , and DAY (= 86,400) convert to the desired units.

The term  $Q_4$  is interpreted as the effective moisture just above the surface, and the terms in WET represent the effective surface moisture. The entire term in [ ] thus represents the vertical moisture gradient near the earth's surface. As shown in the map on the right, most of the evaporation occurs over the ocean [where the term  $(TGR - T_g)$  is zero], although the evaporation is occasionally negative elsewhere (representing condensation on the surface). See instructions 11220 to 11290, COMP 3, and Chapter II, Subsection F.6, for further details.

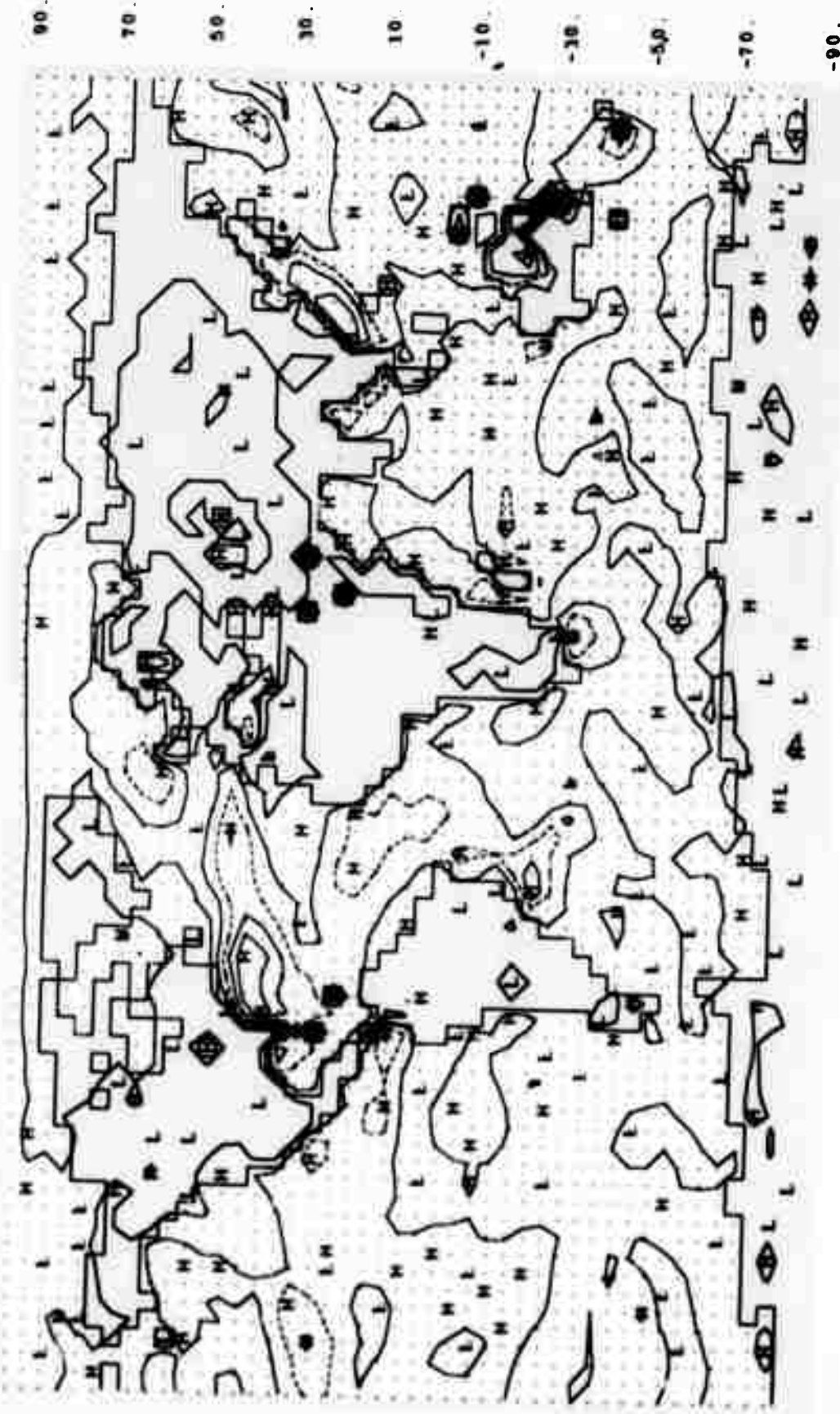


Fig. 4.17 -- Surface evaporation rate. The dashed line is  $10 \text{ mm day}^{-1}$  and the isoline interval is  $5 \text{ mm day}^{-1}$ .

Fig. 4.18. Sensible Heat Flux (Map 15)

(10 ly day<sup>-1</sup>)

This map is calculated from the expression

$$C_D \rho_4 c_p \left( |\vec{V}_s|_{00}^\pi + 2.0 \text{ m sec}^{-1} \right) (T_g - T_4) 10 \text{ DAY}$$

where  $\rho_4$  is the surface air density,  $c_p$  the specific heat at constant pressure,  $T_g$  the (computed) ground temperature (or an assigned ice or ocean surface temperature), and  $T_4$  is the air surface temperature.

The surface drag coefficient  $C_D$  is given by

$$C_D = \begin{cases} \min \left[ \left( 1.0 + 0.07 |\vec{V}_s|_{00}^\pi \right) 10^{-3}, 0.0025 \right], & \text{if ocean} \\ 0.002 + 0.006(z_4/5000 \text{ m}), & \text{otherwise} \end{cases}$$

with  $z_4$  the elevation of the surface. Here  $|\vec{V}_s|_{00}^\pi$  is given in terms of the wind speeds at the four velocity points surrounding a pressure (or temperature) point by the expression (in  $\pi$ -centered notation)

$$|\vec{V}_s|_{00}^\pi = \frac{1}{2} \left[ |\vec{V}_s|_{11}^2 + |\vec{V}_s|_{-11}^2 + |\vec{V}_s|_{-1-1}^2 + |\vec{V}_s|_{1-1}^2 \right]^{1/2}$$

where  $\vec{V}_s = 0.7|\vec{V}_4|$  and  $\vec{V}_4 = \frac{3}{2}\vec{V}_3 - \frac{1}{2}\vec{V}_1$  (the wind extrapolated to level 4). The additive term  $2.0 \text{ m sec}^{-1}$  is an empirical correction for gustiness, and the factor  $10 \text{ DAY} (= 10 \times 86,400)$  converts to the desired units. The sensible heat flux (F4 in the FORTRAN code) is positive when ground temperature is greater than surface air temperature ( $T_g > T_4$ ), representing a heat flux from the ground to the air. As shown in the map on the right, however, this flux is often negative. See instructions 11220 to 11290, COMP 3, and Chapter II, Subsection G.3, for further details.



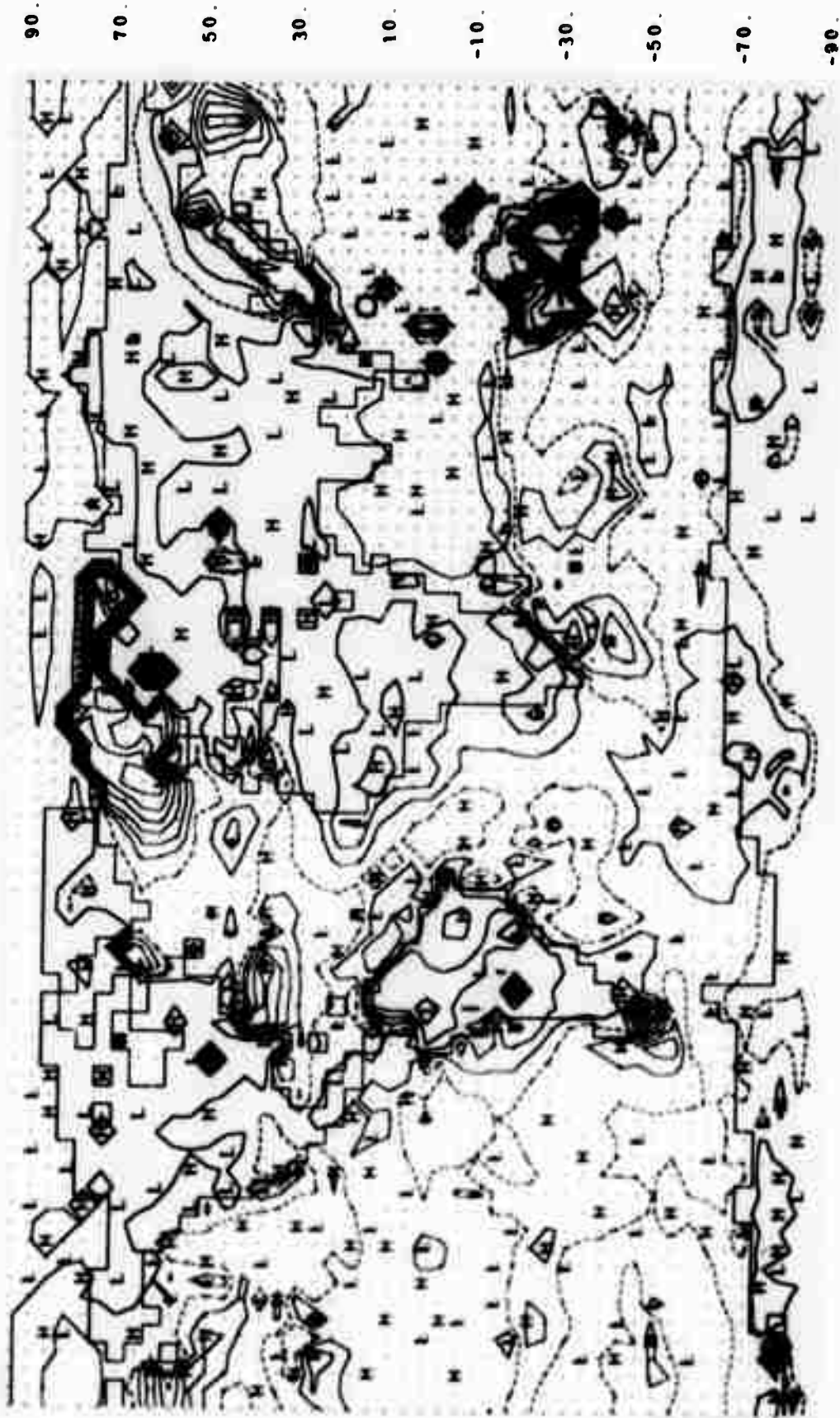


Fig. 6.18 -- Surface sensible heat flux. The dashed line is 0 and the isoline interval is 100 ly day<sup>-1</sup>.

Fig. 4.18a. Lowest-Level Convection (Map 16)

(deg)

This map is calculated from the expression

$$EX = \begin{cases} h_4 - h_3^*, & \text{if } h_4 > h_3^* \text{ and } h_3 \leq h_1^* \\ 0, & \text{otherwise} \end{cases}$$

where the static-energy parameters are given by

$$h_1^* = T_1 + \frac{\phi_1}{c_p} + \frac{L}{c_p} q_s(T_1)$$

$$h_3 = T_3 + \frac{\phi_3}{c_p} + \frac{L}{c_p} q_3$$

$$h_3^* = T_3 + \frac{\phi_3}{c_p} + \frac{L}{c_p} q_s(T_3)$$

$$h_4 = T_4 + \frac{L}{c_p} q_4$$

where  $\phi = gz$  is the geopotential and  $q_s$  is the saturation mixing ratio. The condition  $h_4 > h_3^*$  thus ensures instability between levels 4 and 3, while the condition  $h_3 \leq h_1^*$  ensures stability between levels 3 and 1 (i.e., there is no middle-level convection). Hence  $EX \geq 0$ , and represents the adjustment of the level-4 temperature due to convection. If  $h_4 < h_1^*$  the computed value of  $EX$  is regarded as due to low-level convection, and is used to modify both the lowest-level temperature ( $T_4$ ) and lowest-level heating ( $Q_4$ ). If  $h_4 \geq h_1^*$  the computed value of  $EX$  is regarded as due to penetrating convection, and is used to modify not only  $T_4$  and  $Q_4$  but the heating in the upper and lower layer as well. See Chapter II, Subsection F.3, and instructions 8700 to 9350, COMP 3, for further details.

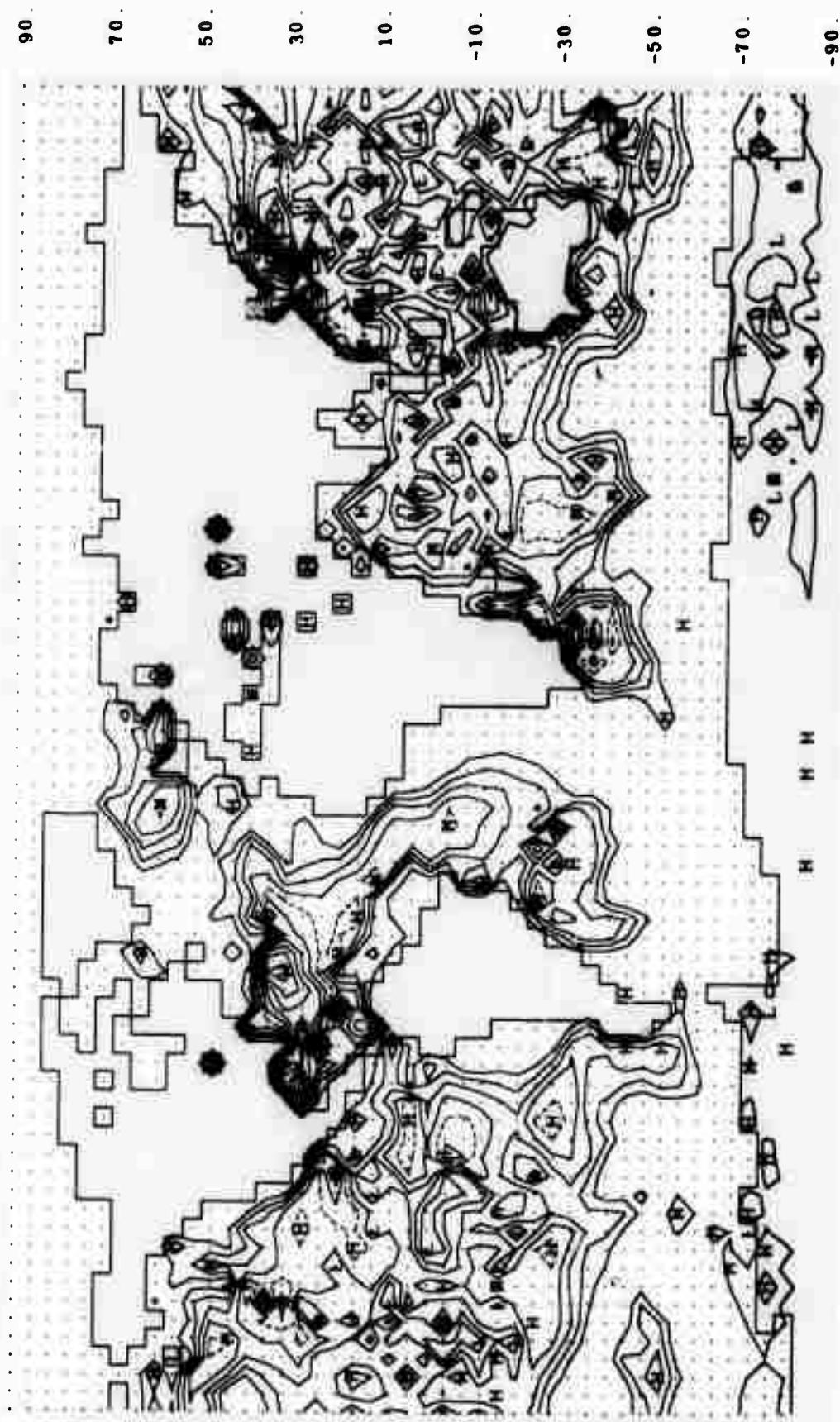


Fig. 4.18a -- Lowest-level convection. The dashed line is 10.0 deg and the isoline interval is 2.0 deg.

Fig. 4.19. Long-Wave Heating in Layers (Map 19)

(deg day<sup>-1</sup>)

This map is calculated from the expressions

$$(R_2 - R_0) \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0 \leq \sigma < 0.5$$

$$(R_4 - R_2) \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0.5 \leq \sigma \leq 1$$

for an arbitrary  $\sigma$  surface, where  $R_0$ ,  $R_2$ ,  $R_4$  are the upward long-wave radiation fluxes at the levels  $\sigma = 0, 1/2, 1$ , respectively. The difference  $(R_2 - R_0)$  is thus the net long-wave radiation absorbed in the upper layer  $\sigma = 0$  to  $\sigma = 1/2$ , and  $(R_4 - R_2)$  is the net long-wave radiation absorbed in the lower layer  $\sigma = 1/2$  to  $\sigma = 1$ . Usually this heating is negative, representing a net long-wave cooling. The factor  $(2g/\pi)^{-1}$  represents the air mass in either the upper or lower layer (per unit area), and  $c_p$  is the air's specific heat at constant pressure. Thus, depending upon whether  $\sigma < 1/2$  or  $\sigma \geq 1/2$ , either one of two versions of this map is produced. See Chapter II, Section G, and instructions 9750 to 10230, COMP 3, for further details.

Layer shown in map at right: upper layer.

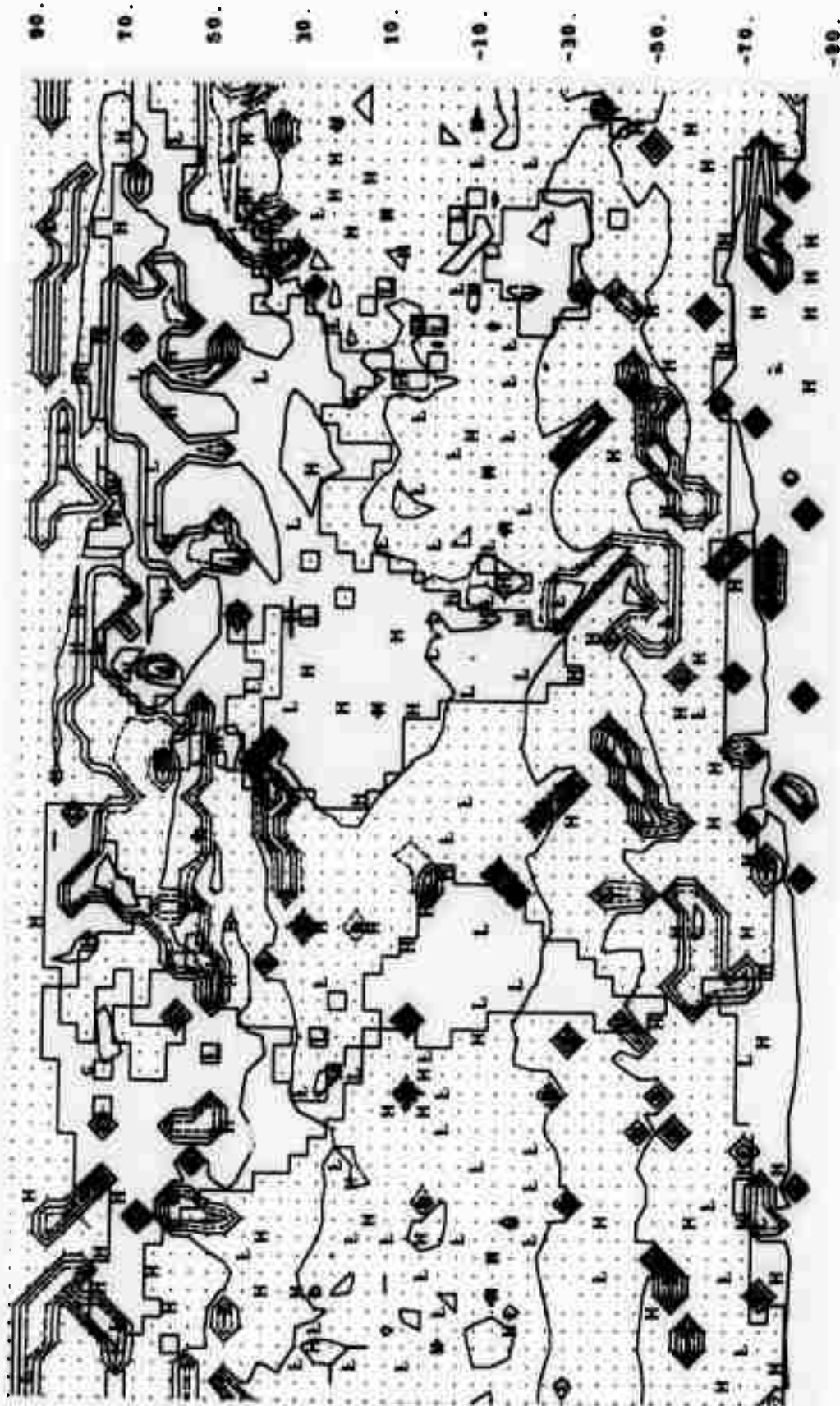


Fig. 4.19 -- Long-wave radiative heating rate in upper layer ( $\sigma = 0$  to  $\sigma = 1/2$ ). The dashed line is  $-2.0 \text{ deg day}^{-1}$  and the isoline interval is  $0.5 \text{ deg day}^{-1}$ .

Fig. 4.20. Long-Wave Heating in Layers (Map 19)  
(deg day<sup>-1</sup>)

This map is calculated from the expressions

$$(R_2 - R_0) \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0 \leq \sigma < 0.5$$

$$(R_4 - R_2) \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0.5 \leq \sigma \leq 1$$

for an arbitrary  $\sigma$  surface, where  $R_0$ ,  $R_2$ ,  $R_4$  are the upward long-wave radiation fluxes at the levels  $\sigma = 0$ ,  $1/2$ ,  $1$ , respectively. The difference  $(R_2 - R_0)$  is thus the net long-wave radiation absorbed in the upper layer  $\sigma = 0$  to  $\sigma = 1/2$ , and  $(R_4 - R_2)$  is the net long-wave radiation absorbed in the lower layer  $\sigma = 1/2$  to  $\sigma = 1$ . Usually this heating is negative, representing a net long-wave cooling. The factor  $(2g/\pi)^{-1}$  represents the air mass in either the upper or lower layer (per unit area), and  $c_p$  is the air's specific heat at constant pressure. Thus, depending upon whether  $\sigma < 1/2$  or  $\sigma \geq 1/2$ , either one of two versions of this map is produced. See Chapter II, Section G, and instructions 9750 to 10230, COMP 3, for further details.

Layer shown in map at right: lower layer.



# MAP 19 ICE IN CONTROL RUN

LONG WAVE HEATING IN LAYERS (DEG CENT/DAY)

INTERVAL = 400.00 TO 400.00

S/P = 0.750 ISOLINES AT -4.000 0.500  
 AU5 DASHED LINE IS -2.00

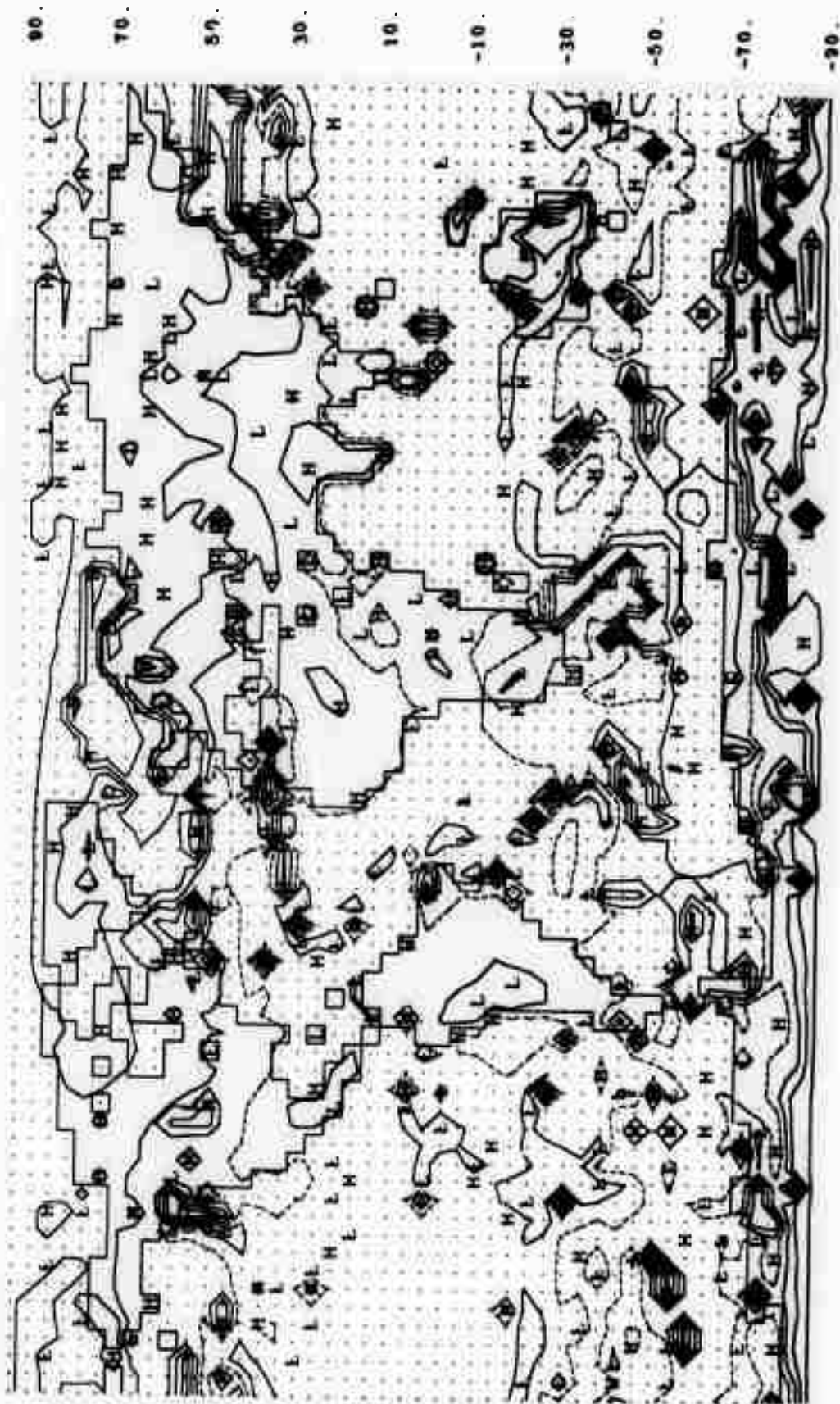


Fig. 4.20 -- Long-wave radiative heating rate in lower layer ( $\sigma = 1/2$  to  $\sigma = 1$ ). The dashed line is  $-2.0 \text{ deg day}^{-1}$  and the isoline interval is  $0.5 \text{ deg day}^{-1}$ .

Fig. 4.21. Short-Wave Absorption (Heating) in Layers (Map 20)  
(deg day<sup>-1</sup>)

This map is calculated from the expressions

$$A_1 \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0 \leq \sigma \leq 0.5$$

$$A_3 \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0.5 < \sigma \leq 1$$

if the cosine of the sun's zenith angle exceeds 0.01. These expressions are replaced by zero if the cosine of the sun's zenith angle is less than or equal to 0.01. Here  $A_1$  and  $A_3$  are the absorbed short-wave radiation in the upper layer ( $\sigma = 0$  to  $\sigma = 1/2$ ) and lower layer ( $\sigma = 1/2$  to  $\sigma = 1$ ), respectively, the factor  $(2g/\pi)^{-1}$  represents the mass (per unit area) in each layer, and  $c_p$  is the specific heat at constant pressure. Thus, depending upon whether the arbitrary value of  $\sigma$  is  $\leq 1/2$  or  $> 1/2$ , either one of two versions of this map is produced. The value of  $A_1$  is the difference between the incoming solar radiation (that part subject to absorption) at the level  $\sigma = 0$  and the downward short-wave flux at the level  $\sigma = 1/2$ . Similarly,  $A_3$  is the difference between the downward fluxes at the levels  $\sigma = 1/2$  and  $\sigma = 1$ . In either version, the short-wave absorption is always positive (or zero) and represents the net short-wave heating within the layers. See Chapter II, Section G, and instructions 10430 to 11010, COMP 3, for further details.

Layer shown in map at right: upper layer.



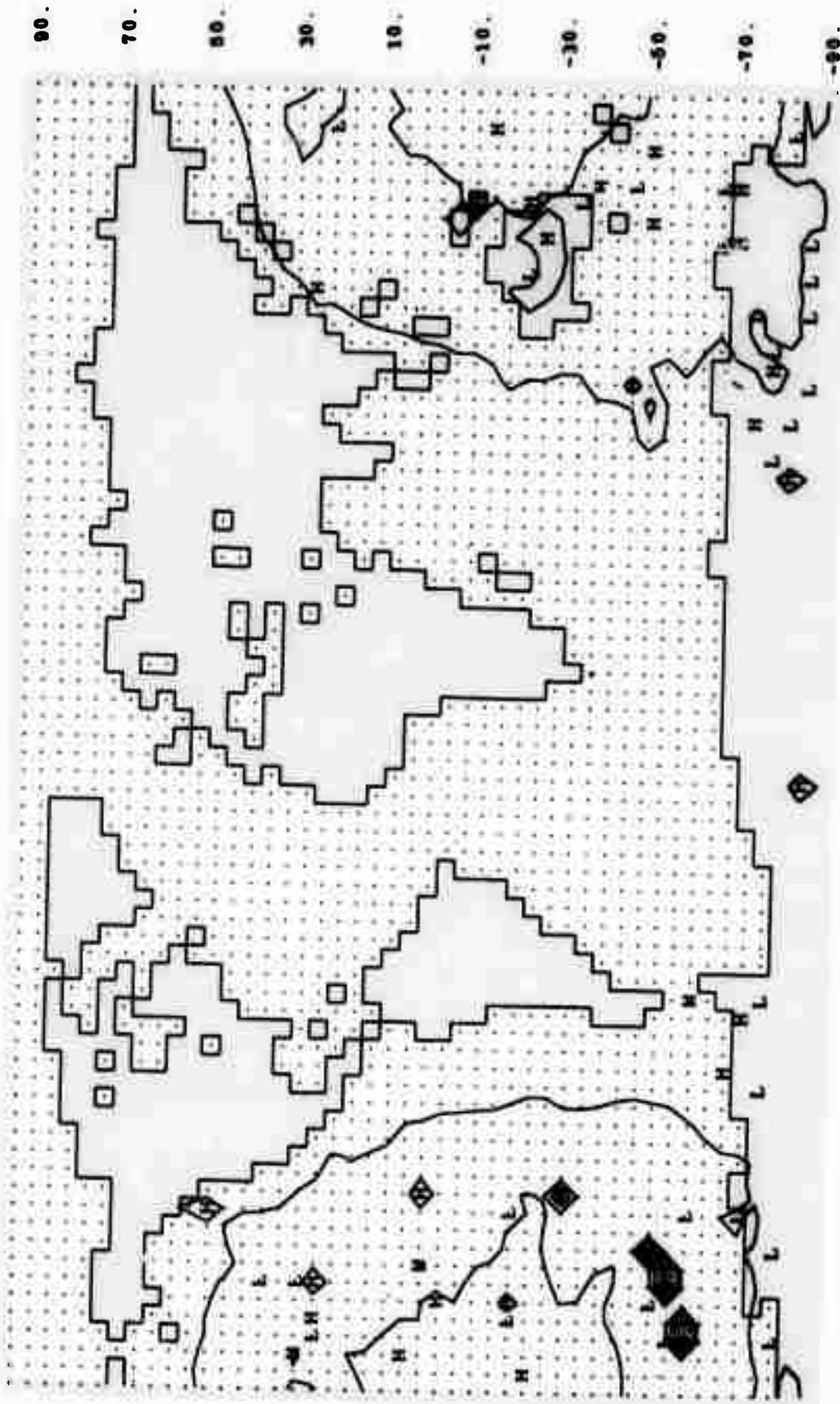


Fig. 4.21 --- Short-wave radiative heating rate in upper layer ( $\sigma = 0$  to  $\sigma = 1/2$ ). The dashed line is 2 deg day<sup>-1</sup> and the isoline interval is 0.5 deg day<sup>-1</sup>.

Fig. 4.22. Short-Wave Absorption (Heating) in Layers (Map 20)

(deg day<sup>-1</sup>)

This map is calculated from the expressions

$$A_1 \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0 \leq \sigma \leq 0.5$$

$$A_3 \left( \frac{2g}{\pi} \right) \frac{1}{c_p} \quad \text{if} \quad 0.5 < \sigma \leq 1$$

if the cosine of the sun's zenith angle exceeds 0.01. These expressions are replaced by zero if the cosine of the sun's zenith angle is less than or equal to 0.01. Here  $A_1$  and  $A_3$  are the absorbed short-wave radiation in the upper layer ( $\sigma = 0$  to  $\sigma = 1/2$ ) and lower layer ( $\sigma = 1/2$  to  $\sigma = 1$ ), respectively, the factor  $(2g/\pi)^{-1}$  represents the mass (per unit area) in each layer, and  $c_p$  is the specific heat at constant pressure. Thus, depending upon whether the arbitrary value of  $\sigma$  is  $\leq 1/2$  or  $> 1/2$ , either one of two versions of this map is produced. The value of  $A_1$  is the difference between the incoming solar radiation (that part subject to absorption) at the level  $\sigma = 0$  and the downward short-wave flux at the level  $\sigma = 1/2$ . Similarly,  $A_3$  is the difference between the downward fluxes at the levels  $\sigma = 1/2$  and  $\sigma = 1$ . In either version, the short-wave absorption is always positive (or zero) and represents the net short-wave heating within the layers. See Chapter II, Section G, and instructions 10430 to 11010, COMP 3, for further details.

Layer shown in map at right: lower layer.

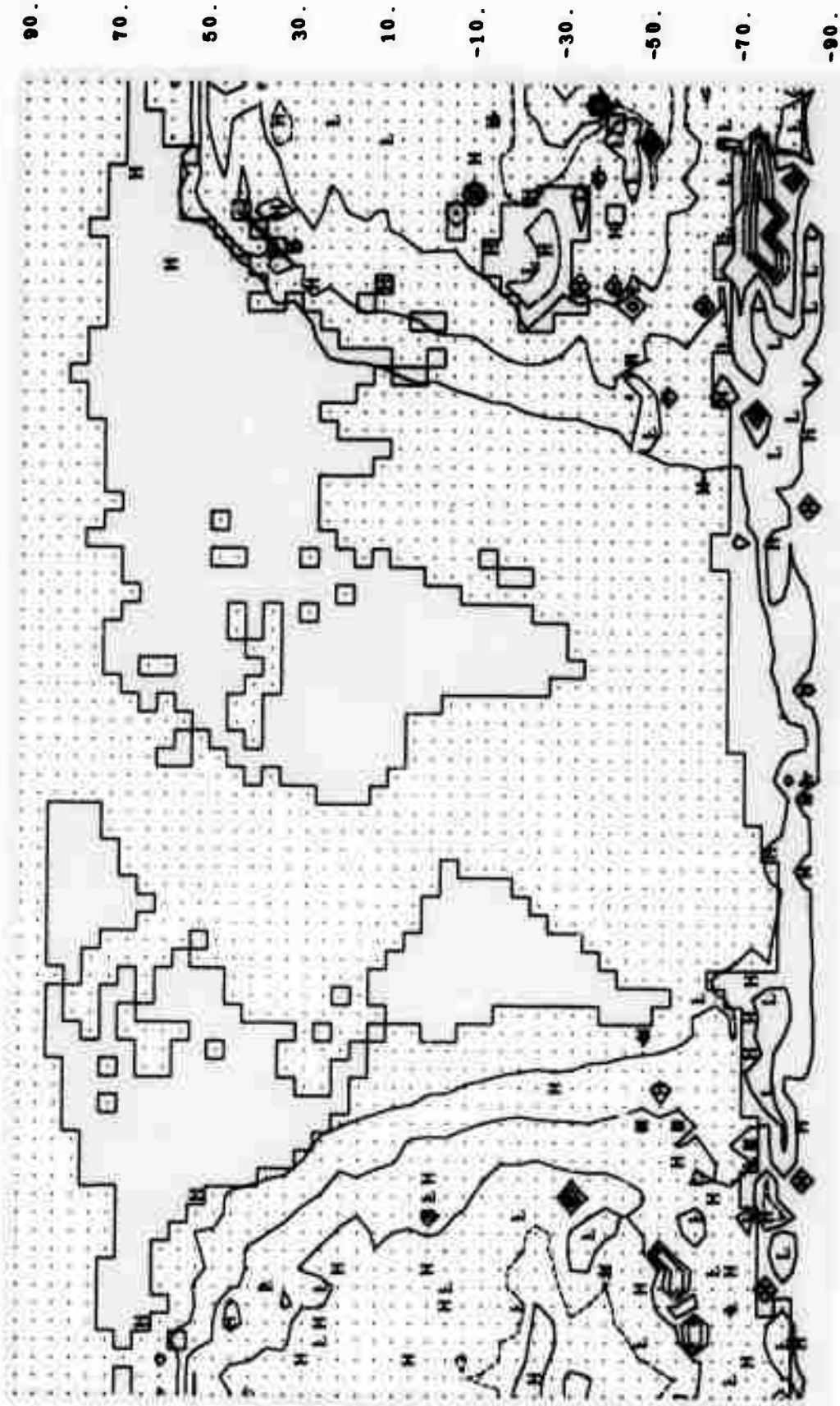


Fig. 4.22 --- Short-wave radiative heating rate in lower layer ( $\sigma = 1/2$  to  $\sigma = 1$ ). The dashed line is  $2 \text{ deg day}^{-1}$  and the isoline interval is  $0.5 \text{ deg day}^{-1}$ .

Fig. 4.23. Surface Short-Wave Absorption (Map 22)

(100 ly day<sup>-1</sup>)

This map is calculated from the expression

$$S_4/100$$

if the cosine of the sun's zenith angle is greater than 0.01, and is set equal to zero if the cosine of the sun's zenith angle is less than or equal to 0.01. Here  $S_4$  is the short-wave radiation absorbed at the surface (or level 4). The effects of surface albedo, atmospheric moisture, and cloudiness are taken into account. The surface short-wave heating is always positive (or zero), and represents the net absorption of insolation at the surface. See Chapter II, Section G, and instructions 10430 to 11010, COMP 3, for further details.

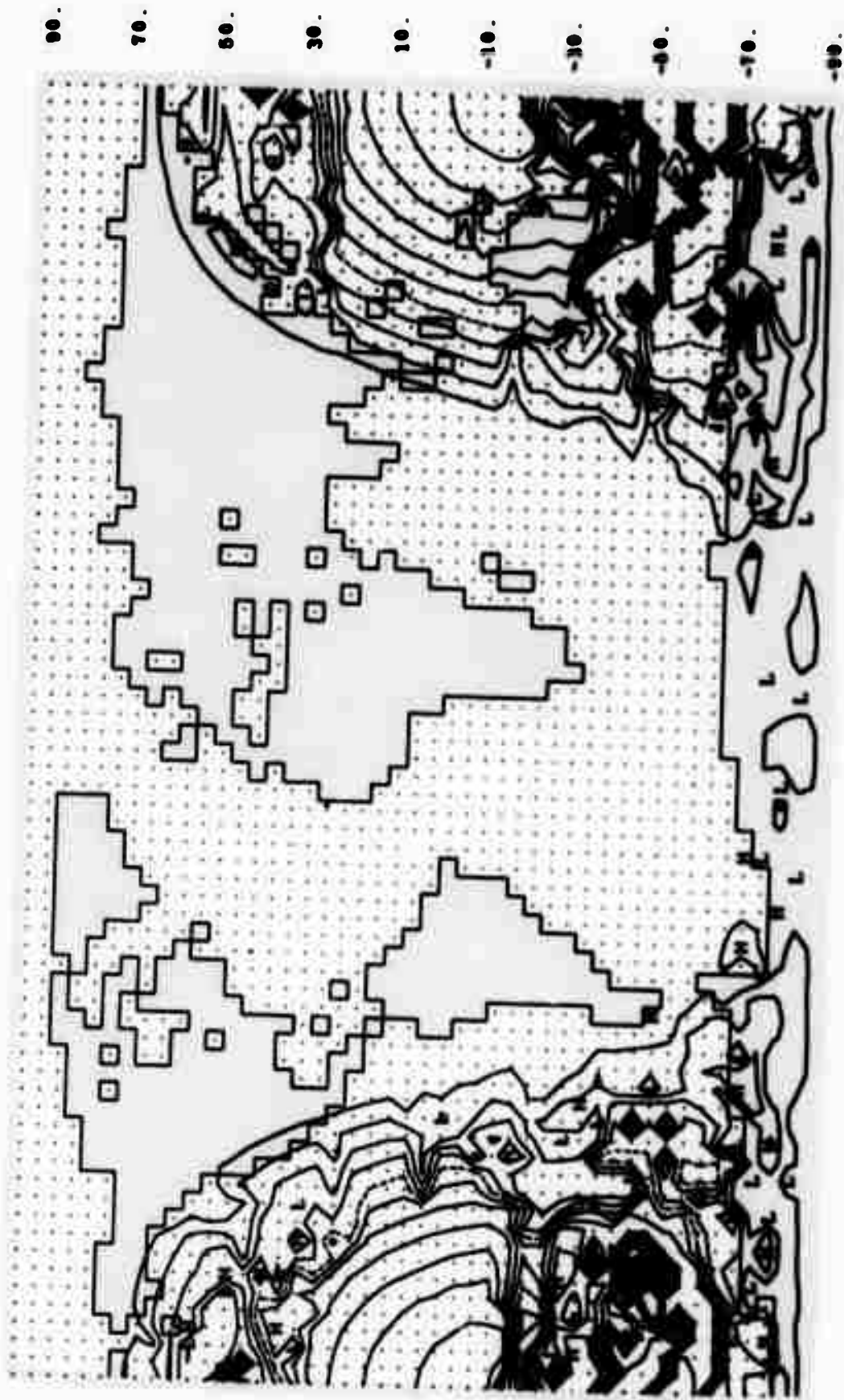


Fig. 4.23 -- Short-wave radiation absorbed at the surface. The dashed line is 1000 ly day<sup>-1</sup> and the isoline interval is 200 ly day<sup>-1</sup>.

Fig. 4.24. Surface Air Temperature (Map 23)  
(deg C)

This map is calculated from the expression

$$T_4 - 273.1 \text{ deg}$$

where  $T_4$  is the air temperature at the surface (level 4). Since  $T_4$ , like other dependent temperature variables, is in deg K, this expression serves simply to convert the surface air temperature into the units deg C. The value of  $T_4$  resembles the extrapolated value  $\frac{3}{2} T_3 - \frac{1}{2} T_1$  (where  $T_3$  and  $T_1$  are the air temperatures at levels 3 and 1, respectively), but also incorporates the surface air temperature adjustments introduced by low-level convection and latent heating. See Chapter II, Section G, and instructions 8970 to 9130 in subroutine COMP 3 for further details.

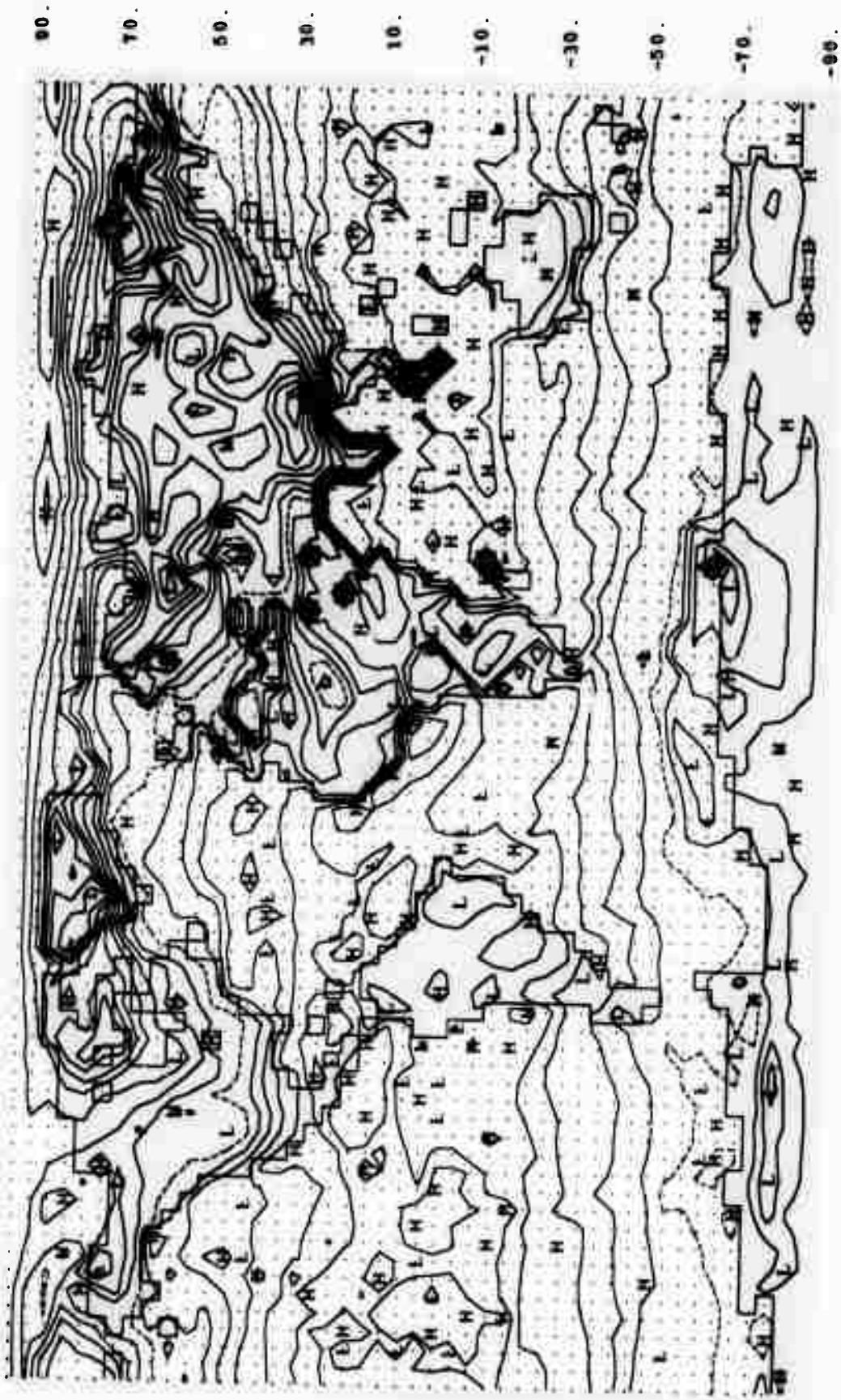


Fig. 4.24 -- Surface air temperature. The dashed line is 0 deg C and the isoline interval is 5 deg C.

Fig. 4.25. Ground Temperature (Map 24)

(deg C)

This map is calculated from the ground-temperature ( $T_{gr}$ ) dependence of the terms in the surface heat-balance equation, assuming the ground to be a perfect insulator of zero heat capacity:

$$R_4 + \Gamma + H_E - S_g = 0$$

Here the surface long-wave cooling  $R_4$  is given by  $\tilde{R}_4 + \sigma(T_{gr}^4 - T_g^4)$ , the surface sensible heat flux  $\Gamma$  by  $C_\Gamma(T_{gr} - T_4)$ , the latent heat flux from surface evaporation  $H_E$  by  $C_\Gamma(q_{se} - q_4)L/c_p$ , and  $S_g$  is the solar radiation absorbed at the surface. Here  $\tilde{R}_4$  is a preliminary determination of the surface long-wave cooling, and  $T_{gr}$  is a revised or improved value of the ground temperature  $T_g$ . For further details, see Chapter II, Subsection G.3.

Over ice- or snow-covered land and over sea ice,  $T_{gr}$  is not allowed to exceed  $T_o (= 273.1^\circ K)$ . Over sea ice this balance is altered to include a heat flux into the sea ice given by  $-B(T_{gr} - T_o)$ , where  $B$  is an assumed ice conduction coefficient. Over open ocean the ground temperature  $T_{gr}$  is taken equal to the assigned sea-surface temperature  $T_g = TG00$  (see Fig. 3.14), and there is thus no ground-temperature correction to either the surface long-wave radiation ( $R_4 = \tilde{R}_4$ ) or to the surface saturated mixing ratio ( $q_{se} = q_s$ ).



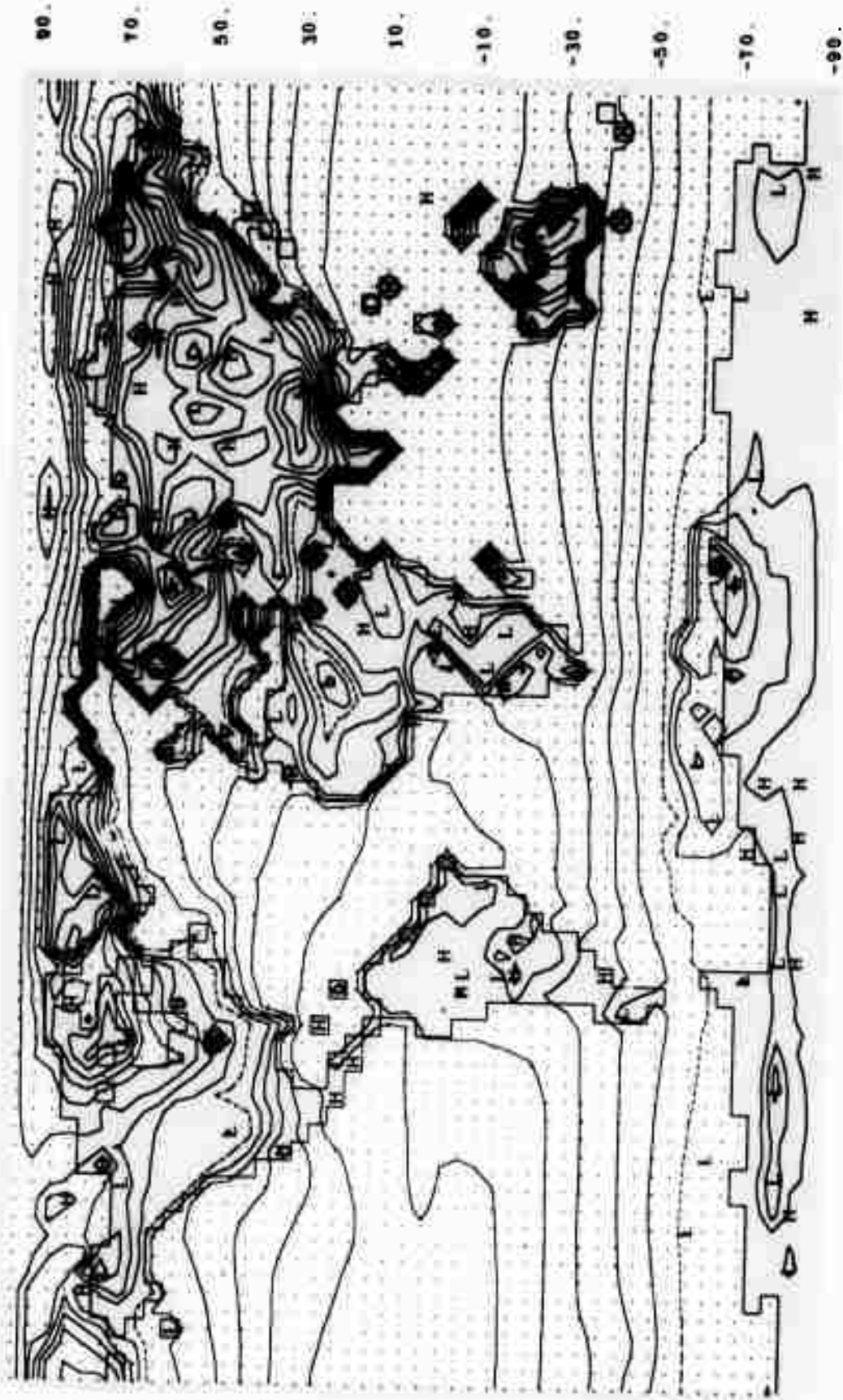


Fig. 4.25 -- Ground temperature. The dashed line is 0 deg C and the isoline interval is 5 deg C.

Fig. 4.26. Ground Wetness (Map 25)

(dimensionless)

This map is calculated from the expression  $GW = 10 \text{ WET}$ , where WET is assigned the value 1.0 (saturated) over ocean, ice, and snow surfaces, and is calculated over (bare) land surfaces according to

$$WET = (GW)_{\text{new}} = (GW)_{\text{old}} + (1 - \text{runoff}) (\Delta q_3)_{\text{TOTAL}} \frac{1}{GWM} \frac{\pi}{2g},$$

in which the old or previous value of GW is altered according to the surface water balance. Here  $(\Delta q_3)_{\text{TOTAL}} = (E - C)(2g/\pi)5\Delta t$  is the total moisture change (over  $5\Delta t$ ) including the effects of evaporation and both large-scale and convective condensation, and GWM is an assumed constant ground-water mass ( $= 30 \text{ g cm}^{-2}$ ). The runoff factor varies between 0 and 1, and is taken as  $0.5(GW)_{\text{old}}$  if  $(GW)_{\text{old}} < 1$  (unsaturated surface), and as unity if  $(GW)_{\text{old}} = 1$  (saturated), provided  $(\Delta q_3)_{\text{TOTAL}} > 0$  in either case. If  $(\Delta q_3)_{\text{TOTAL}} < 0$ , representing an increase in level-3 moisture and a decrease of surface moisture, then the runoff is taken as zero. See Chapter II, Subsection F.5, for further details.

If  $(GW)_{\text{new}} < 0$  it is set to zero, and if  $(GW)_{\text{new}} > 1$  it is set to unity. The resulting wetness is then multiplied by 10 in order to scale the final GW from 0 to 10.

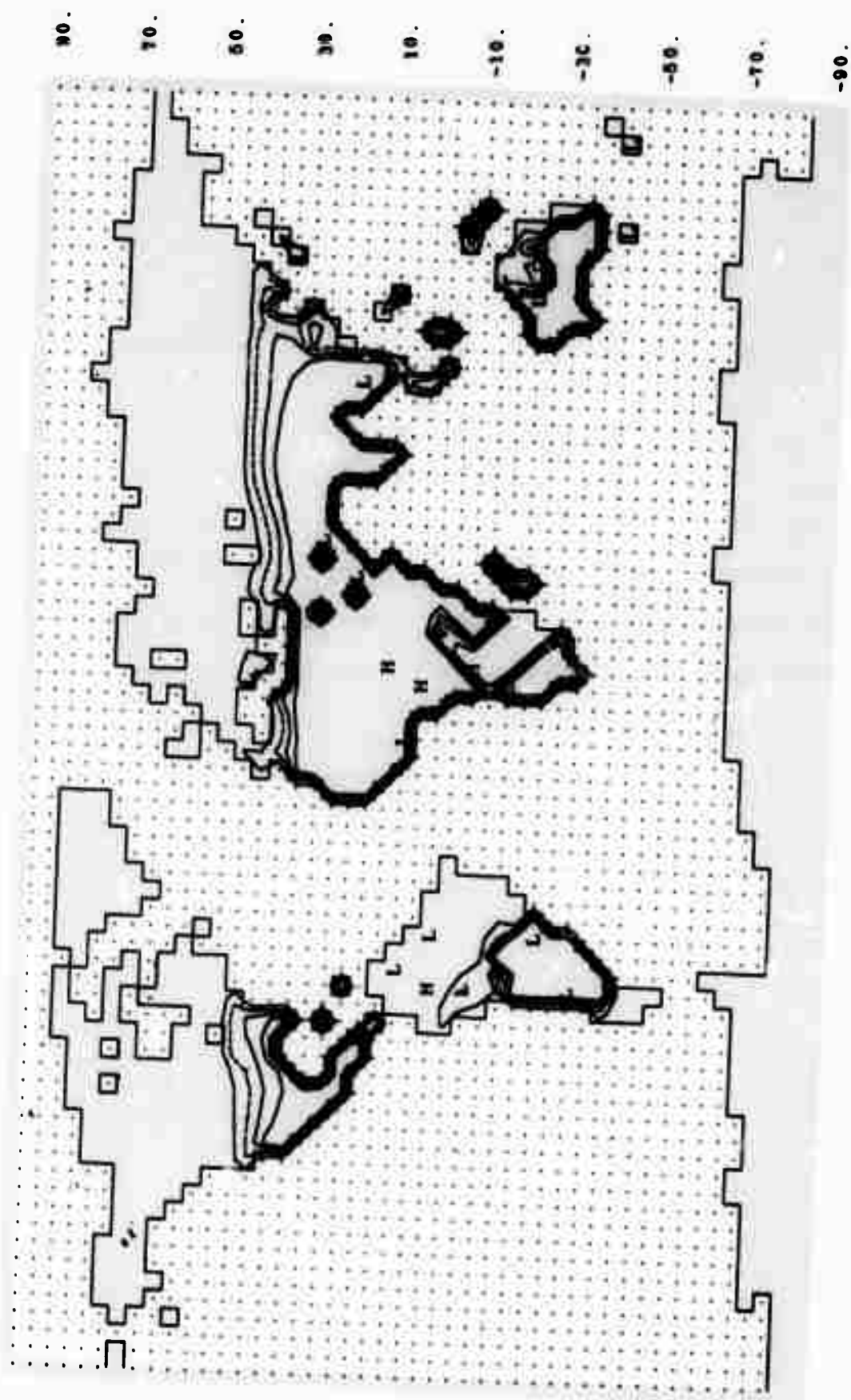


Fig. 4.26 -- Ground wetness, scaled 0 to 10. The dashed line is 6.0 and the isoline interval is 2.0.

Fig. 4.27. High Cloudiness (Map 26)  
(dimensionless)

This version of Map 26 is calculated from the expression

$$CL1 = \min(-1.3 + 2.6RH_3, 1)$$

where  $RH_3$  is the level-3 relative humidity (as in Map 11). If  $CL \leq 0$  the sky is assumed to be clear and CL is reset to zero; otherwise CL1 is taken as the fraction of the sky covered with high or type-1 clouds. This cloudiness measure may be identified with towering cumulus between the levels 3 and 1, and is associated with either middle-level or penetrating convection. If there is no such convection, there is no type-1 or high cloudiness ( $CL1 = 0$ ). For identification, this cloudiness is assigned the index  $\sigma = 1/4$  in the map-generating program in Chapter VII. See Chapter II, Subsection F.6, for further details.

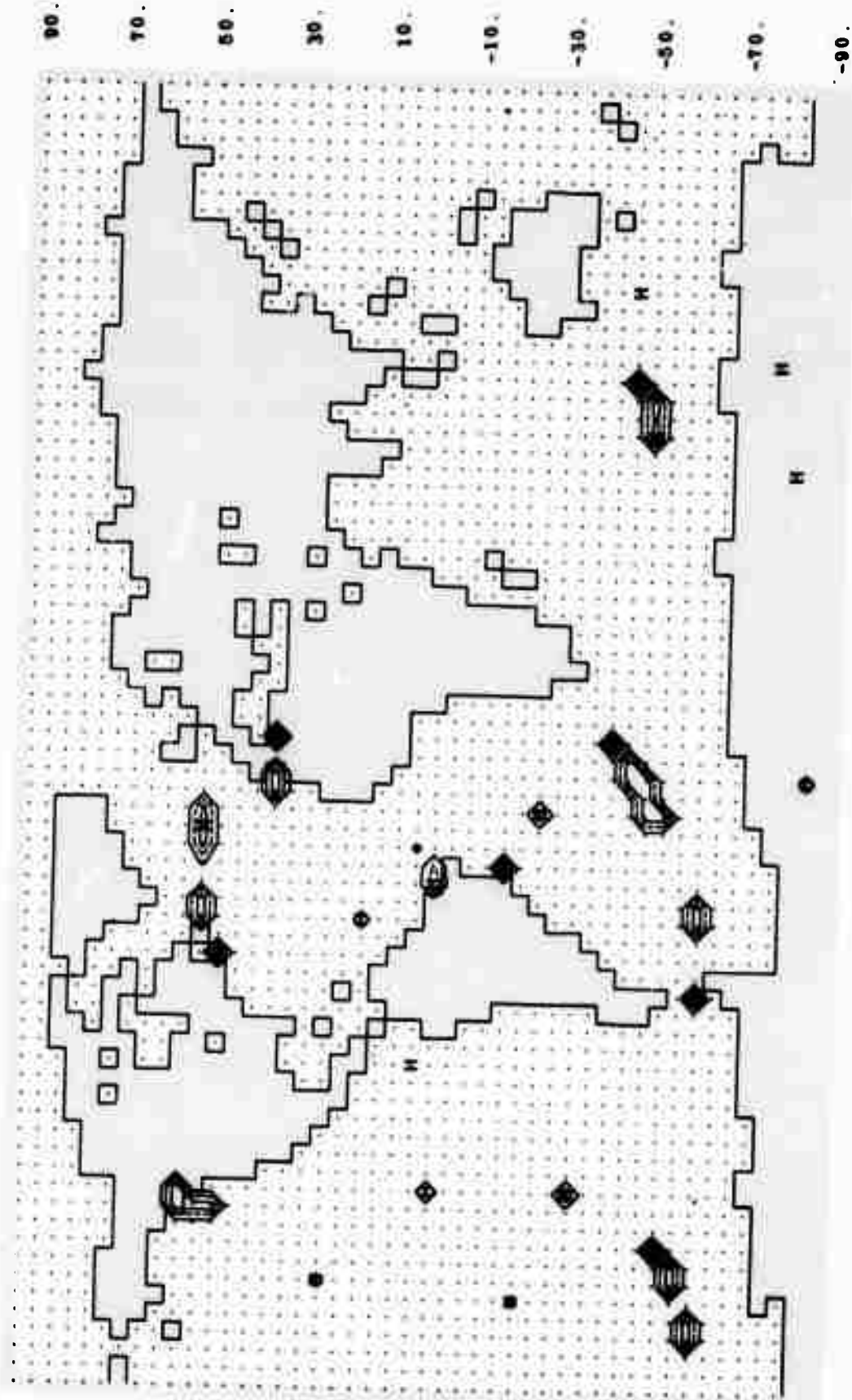


Fig. 4.27 -- High cloudiness, scaled  $\leq 1$ . The dashed line is 0.5 and the isoline interval is 0.3.

Fig. 4.28. Middle Cloudiness (Map 26)

(dimensionless)

This version of Map 26 is calculated on the basis of  $CL2 = 1$  if there is large-scale precipitation (and if there is no penetrating convection or high cloudiness,  $CL1 = 0$ ). Under all other conditions  $CL2 = 0$ . Thus this measure of cloudiness is either 0 or 1 at all points. We may regard  $CL2$  as the fraction of the sky covered by type-2 clouds, which are identified as heavy overcast between levels 3 and 2. For identification, this cloudiness is assigned the index  $\sigma = 3/4$  in the map-generating program in Chapter VII. See Chapter II, Subsection F.6, for further details.

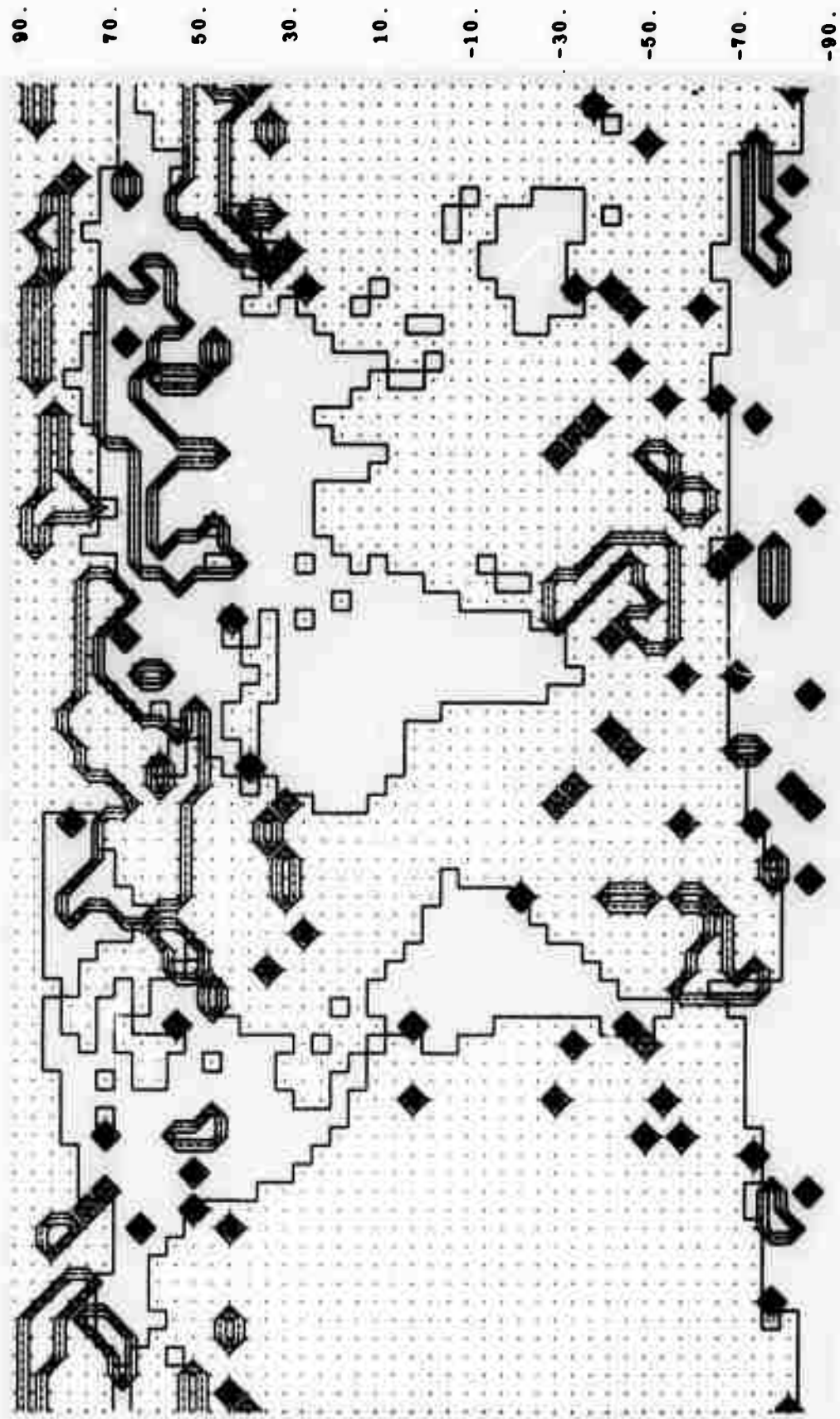


Fig. 4.28 -- Middle cloudiness, scaled 0 or 1. The dashed line is 0.5 and the isoline interval is 0.3.

Fig. 4.29. Low Cloudiness (Map 26)  
(dimensionless)

This version of Map 26 is calculated from the expression

$$CL3 = \min(-1.3 + 2.6RH_3, 1)$$

where  $RH_3$  is the level-3 relative humidity (as in Map 11). If  $CL3 \leq 0$  the sky is assumed to be clear and  $CL3$  is reset to zero; otherwise  $CL3$  is taken as the fraction of the sky covered with low or type-3 clouds. This cloudiness measure may be identified with shallow cumulus at level 3, and is associated with low-level convection. If there is no low-level convection, there is no low cloudiness ( $CL3 = 0$ ); there is also no low cloudiness if there is any high cloudiness (as in Fig. 4.27). For identification, this cloudiness is assigned the index  $\sigma = 1$  in the map-generating program in Chapter VII. See Chapter II, Subsection F.6, for further details.



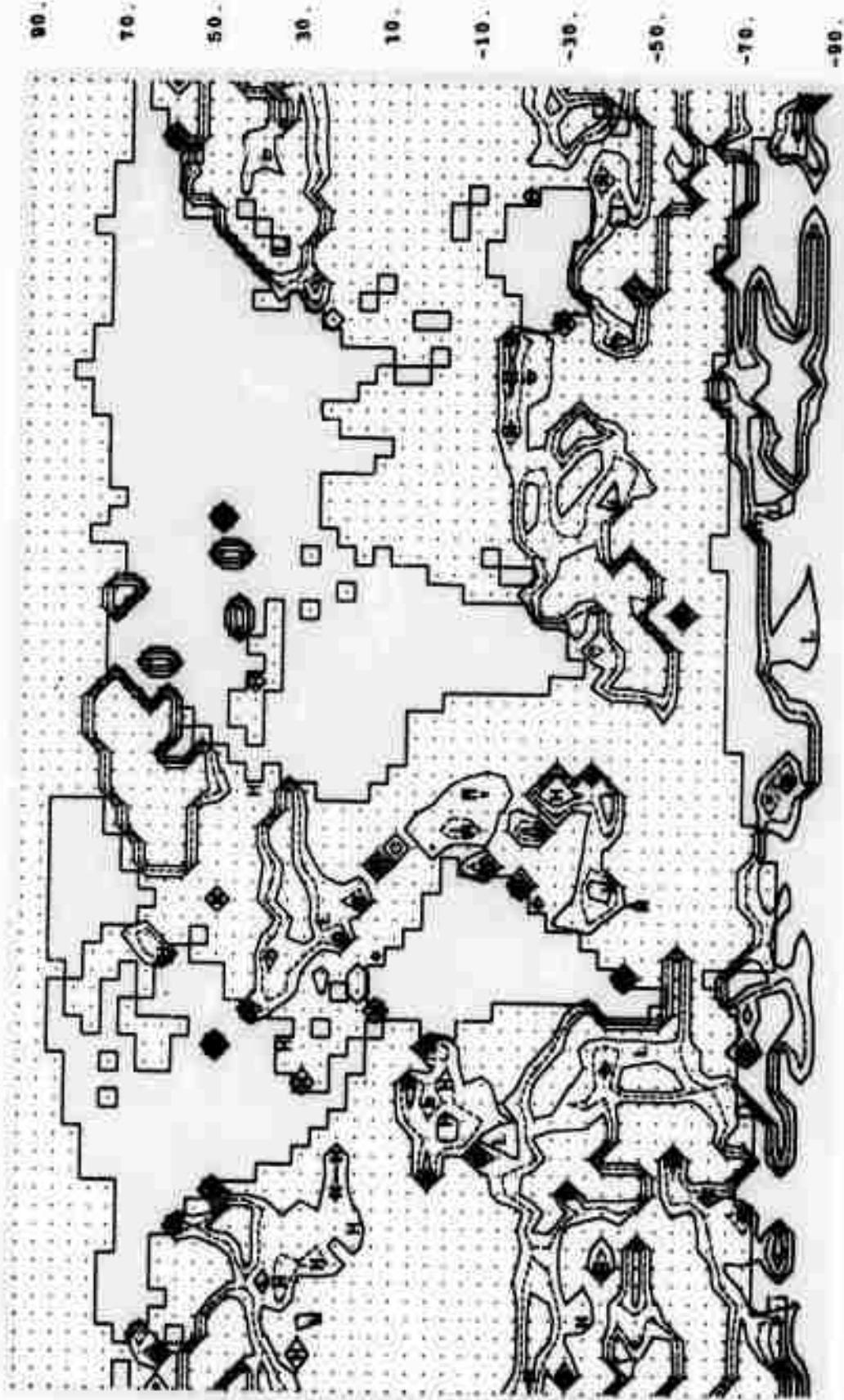


Fig. 4.29 -- Low cloudiness, scaled  $\leq 1$ . The dashed line is 0.5 and the isoline interval is 0.3.

Fig. 4.29a. Total Convective Heating in Layers (Map 28)

(deg day<sup>-1</sup>)

This map is calculated from the expression

$$2 \left\{ \left[ (\Delta T_1)_{CM} + (\Delta T_1)_{CP} \right] \left( \frac{3}{4} - \sigma \right) + \left[ (\Delta T_3)_{CM} + (\Delta T_3)_{CP} \right] \left( \sigma - \frac{1}{4} \right) \right\} 48$$

where  $(\Delta T_1)_{CM}$  and  $(\Delta T_1)_{CP}$  are the temperature changes (over  $5\Delta t$ ) due to middle-level and penetrating convective heating, respectively, in the upper layer [with  $(\Delta T_3)_{CM}$  and  $(\Delta T_3)_{CP}$  similarly defined for the lower layer]. The factor 48 converts to the desired units, and the factor 2 represents  $(\sigma_3 - \sigma_1)^{-1}$ . For  $\sigma$  other than  $\sigma_1 (= 1/4)$  and  $\sigma_3 (= 3/4)$ , this map thus generates the convective heating rate by linear interpolation and extrapolation in  $\sigma$  (or  $p$ ) space. If a  $p$  surface is requested,  $\sigma$  in the above expression is replaced by  $(p - p_T)/\pi$ . See Chapter II, Section F, and instructions 11410 to 11490, COMP 3, for further details.

Layer shown in map at right: upper layer.

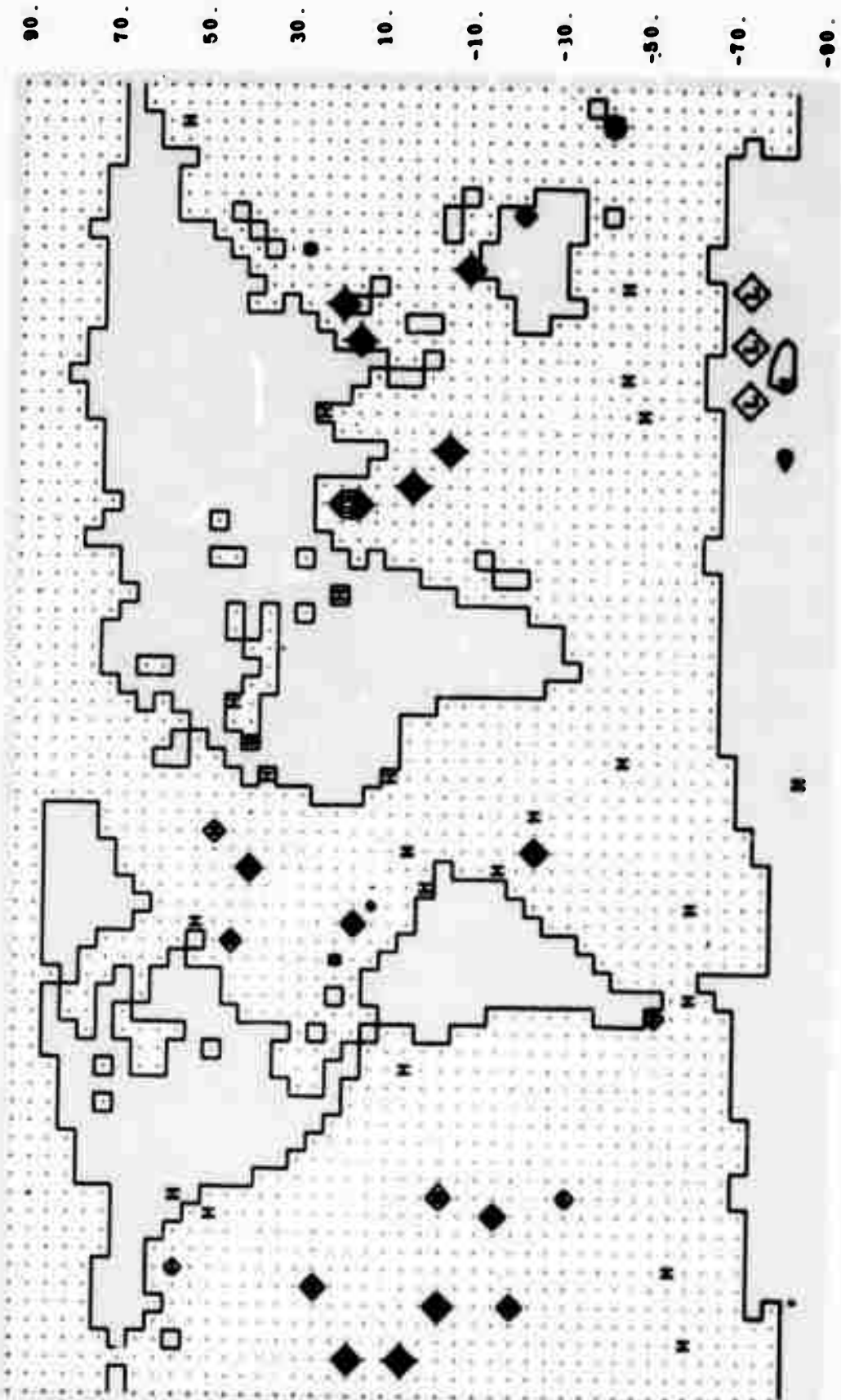


Fig. 4.29a -- Total convective heating in the upper layer ( $\sigma = 0$  to  $\sigma = 1/2$ ). The dashed line is 0 and the isoline interval is 0.2 deg day<sup>-1</sup>.

Fig. 4.29b. Total Convective Heating in Layers (Map 28)

(deg day<sup>-1</sup>)

This map is calculated from the expression

$$2 \left\{ \left[ (\Delta T_1)_{CM} + (\Delta T_1)_{CP} \right] \left( \frac{3}{4} - \sigma \right) + \left[ (\Delta T_3)_{CM} + (\Delta T_3)_{CP} \right] \left( \sigma - \frac{1}{4} \right) \right\} 48$$

where  $(\Delta T_1)_{CM}$  and  $(\Delta T_1)_{CP}$  are the temperature changes (over  $5\Delta t$ ) due to middle-level and penetrating convective heating, respectively, in the upper layer [with  $(\Delta T_3)_{CM}$  and  $(\Delta T_3)_{CP}$  similarly defined for the lower layer]. The factor 48 converts to the desired units, and the factor 2 represents  $(\sigma_3 - \sigma_1)^{-1}$ . For  $\sigma$  other than  $\sigma_1 (= 1/4)$  and  $\sigma_3 (= 3/4)$ , this map thus generates the convective heating rate by linear interpolation and extrapolation in  $\sigma$  (or  $p$ ) space. If a  $p$  surface is requested,  $\sigma$  in the above expression is replaced by  $(p - p_T)/\pi$ . See Chapter II, Section F, and instructions 11410 to 11490, COMP 3, for further details.

Layer shown in map at right: lower layer.

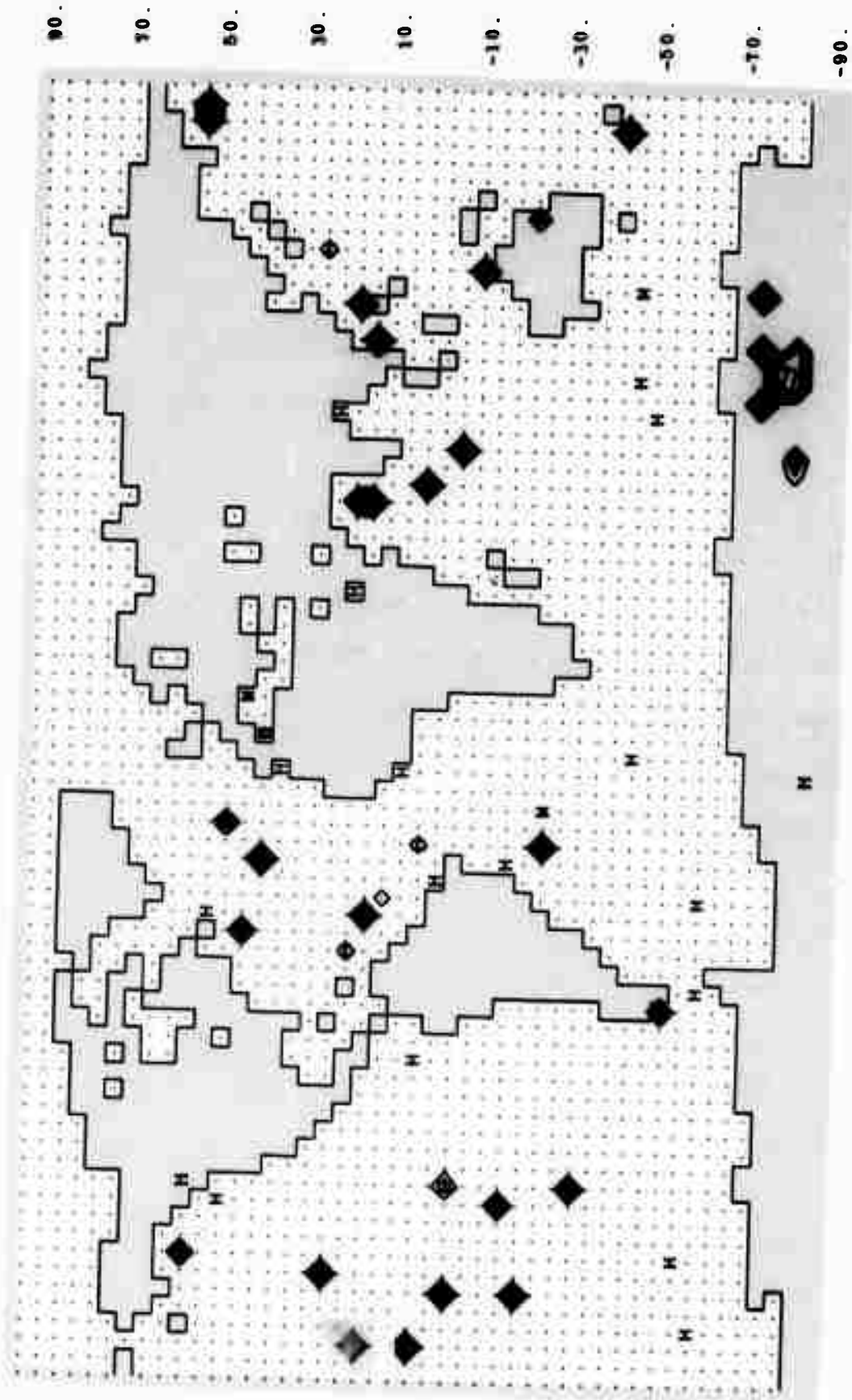


Fig. 4.29b --- Total convective heating in the lower layer ( $\sigma = 1/2$  to  $\sigma = 1$ ). The dashed line is 0 and the isoline interval is 0.2 deg day<sup>-1</sup>.

Fig. 4.29c. Latent Heating (Map 29)  
(deg day<sup>-1</sup>)

This map is calculated from the expression

$$\frac{L}{c_p} (\text{PREC}) 48$$

where PREC is the large-scale condensation (or precipitation) rate (as in Map 9), L is the latent heat of condensation, and  $c_p$  is the air's specific heat at constant pressure. The factor 48 converts to the desired units. This latent heating applies to the lower layer only, as represented by level 3. See Chapter II, Subsection F.2, and instructions 8610 to 8690, COMP 3, for further details.

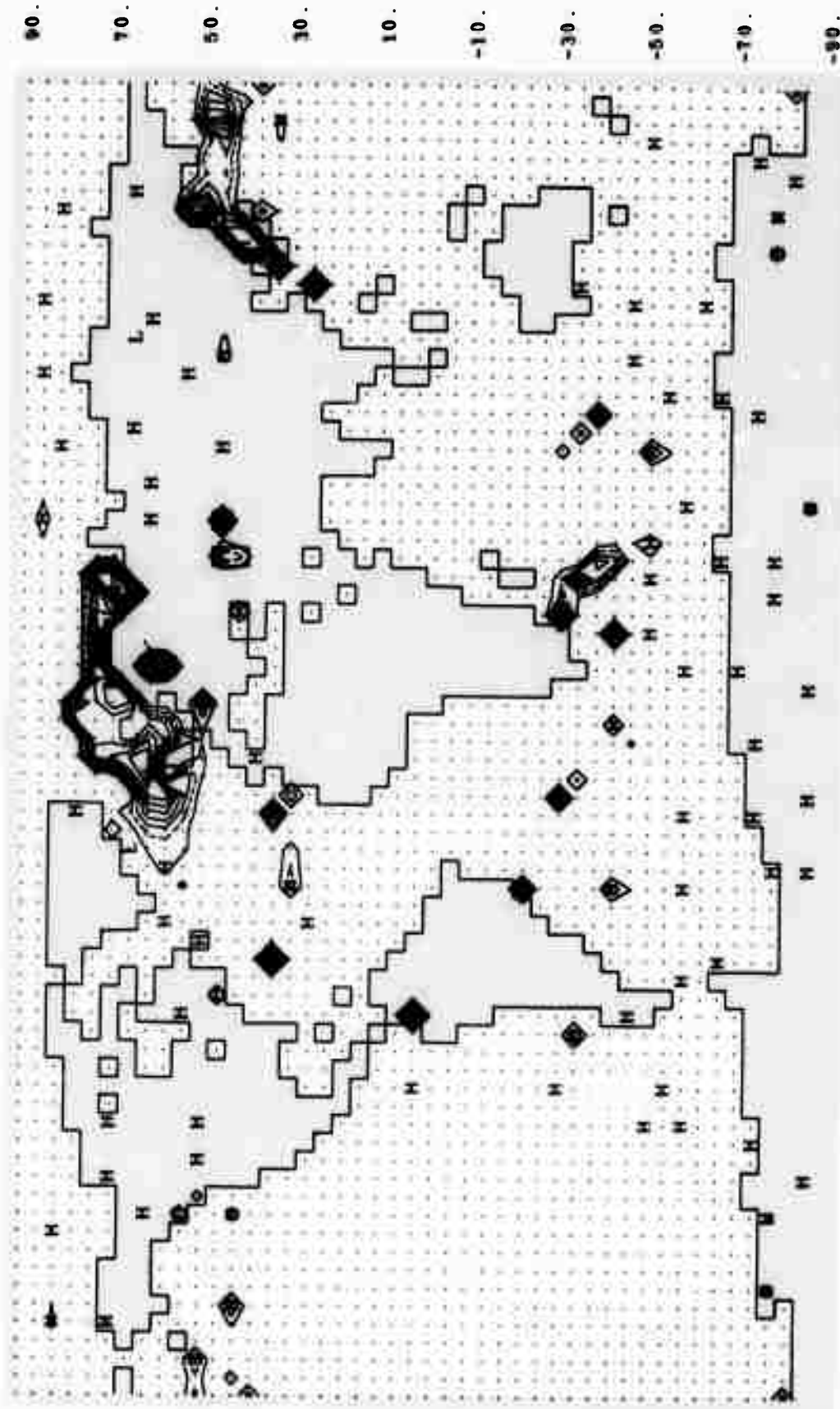


Fig. 4.29c -- Latent heating in the lower layer ( $\sigma = 1/2$  to  $\sigma = 1$ ). The dashed line is  $1.0 \text{ deg day}^{-1}$  and the isoline interval is  $0.5 \text{ deg day}^{-1}$ .

Fig. 4.30. Surface Long-Wave Cooling (Map 30)  
(100 ly day<sup>-1</sup>)

This map is calculated from the expression

$$R_4/100$$

where  $R_4$  is the net upward long-wave radiation at the earth's surface. See Chapter II, Subsection G.2, and instructions 10430 to 11010, COMP 3, for further details.



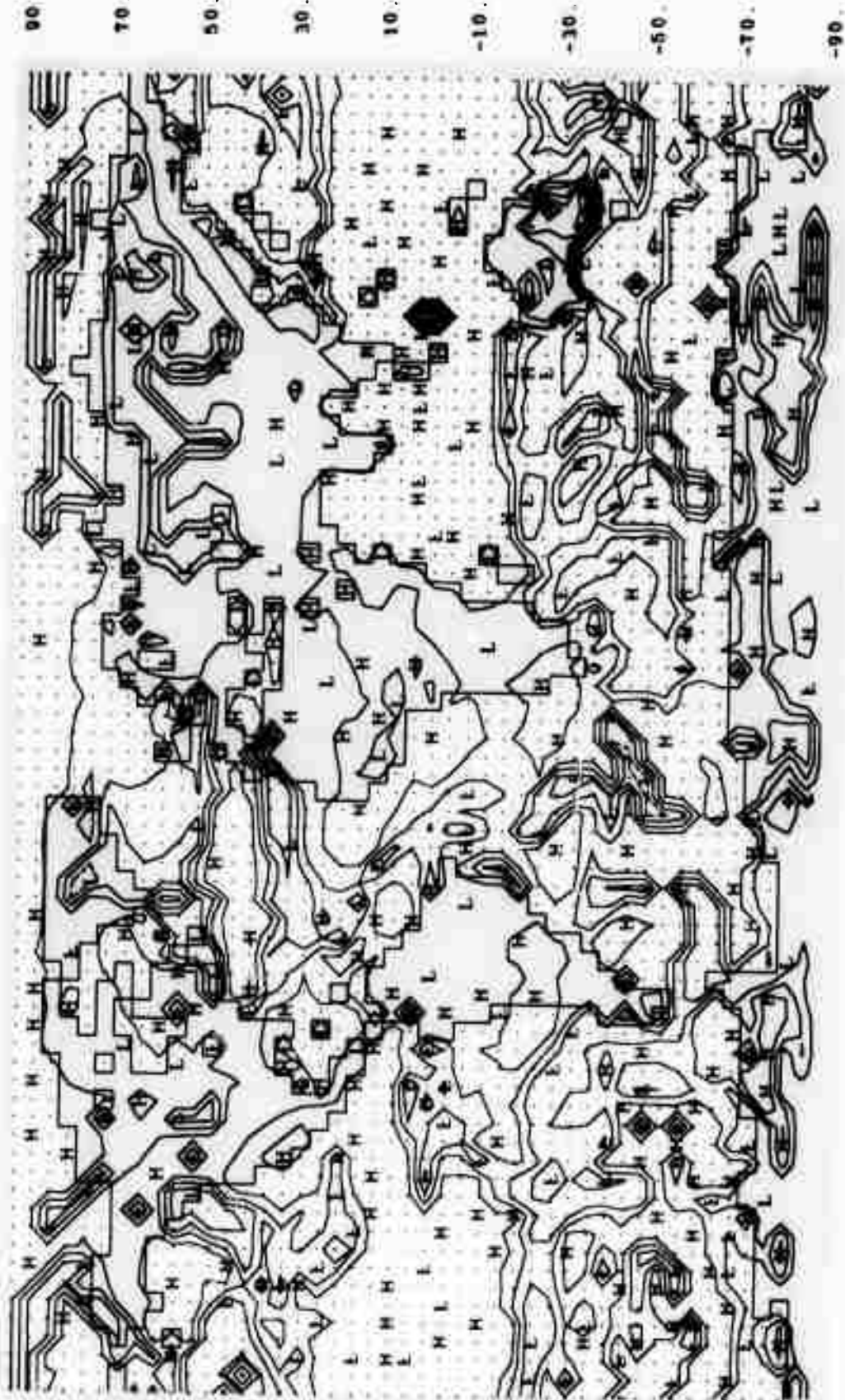


Fig. 4.30 --- Long-wave radiative flux at the surface. The dashed line is 100 ly day<sup>-1</sup> and the isoline interval is 50 ly day<sup>-1</sup>.

Fig. 4.31. Surface Heat Balance (Map 31)

(100 ly day<sup>-1</sup>)

This map is calculated from the expression

$$(S_4 - R_4 - F_4)10^{-2} - (L\rho_w E_4)10^{-3}$$

where  $S_4$  is the short-wave radiation absorbed at the surface (as in Map 22),  $R_4$  is the net upward long-wave radiation at the surface (as in Map 30),  $F_4$  is the upward sensible heat flux from the surface (as in Map 15), and  $E_4$  is the heat expended in evaporation from the surface (as in Map 14). Here  $L$  is the latent heat of evaporation,  $\rho_w$  is the density of water, and the factors  $10^{-2}$  and  $10^{-3}$  serve to convert to the desired units. A positive balance indicates a net downward energy flux at the surface. Since the ground temperature over land (and ice) is itself determined from the condition of a zero surface heat balance, the small but nonzero values for the heat balance seen here over the continents are the result of the use of spatially averaged temperatures in those portions of the subroutine COMP 3 that have been incorporated into the program for Map 30 (see Map Program Listing, Chapter VII, Section B). This imbalance is here less than 10 ly/day, or approximately one percent of the separate heat-balance components. The relatively small heat flux through the ice at the (fixed) locations of ice-covered ocean has also been neglected in producing this map. See Chapter II, Subsection G.3, for further details.

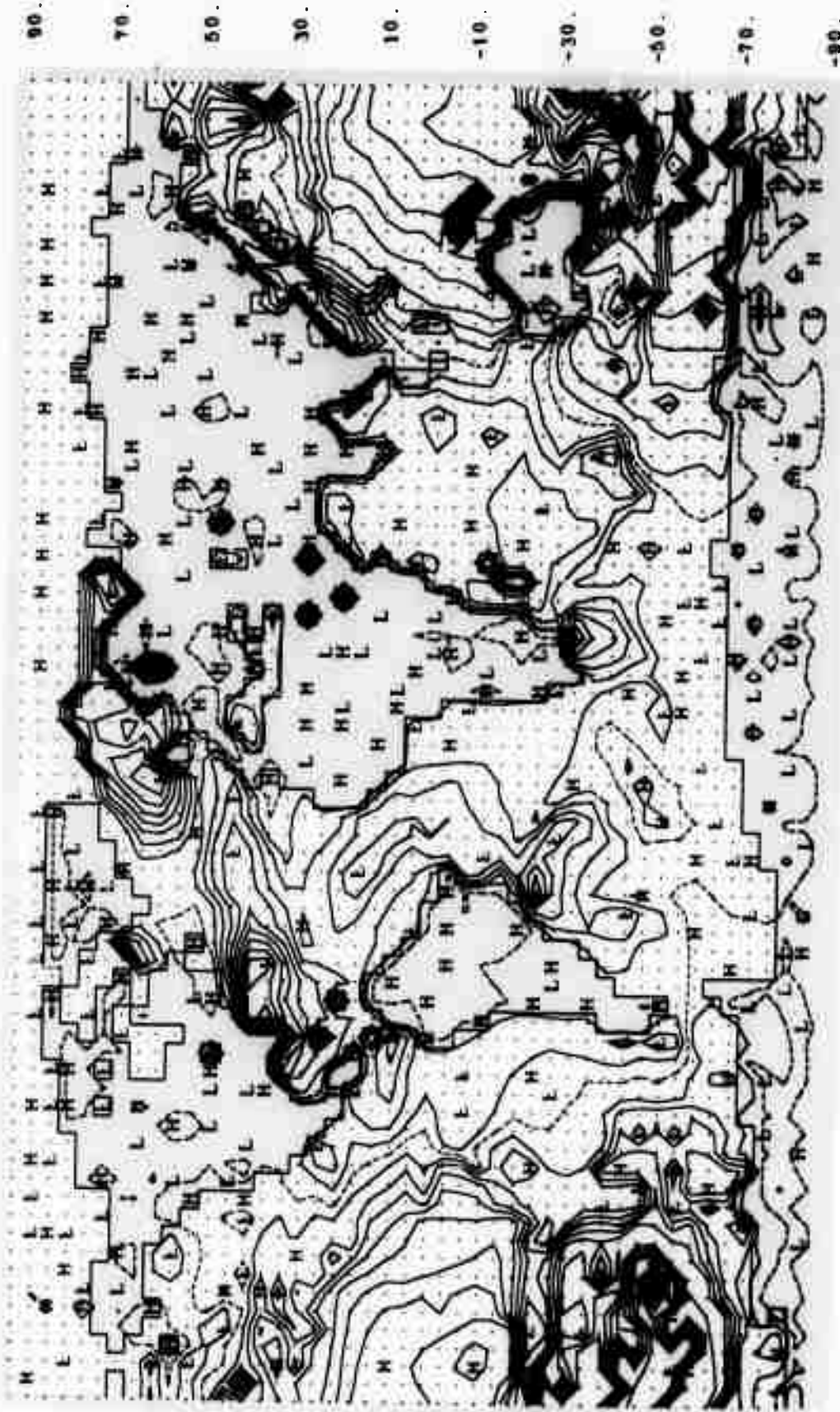
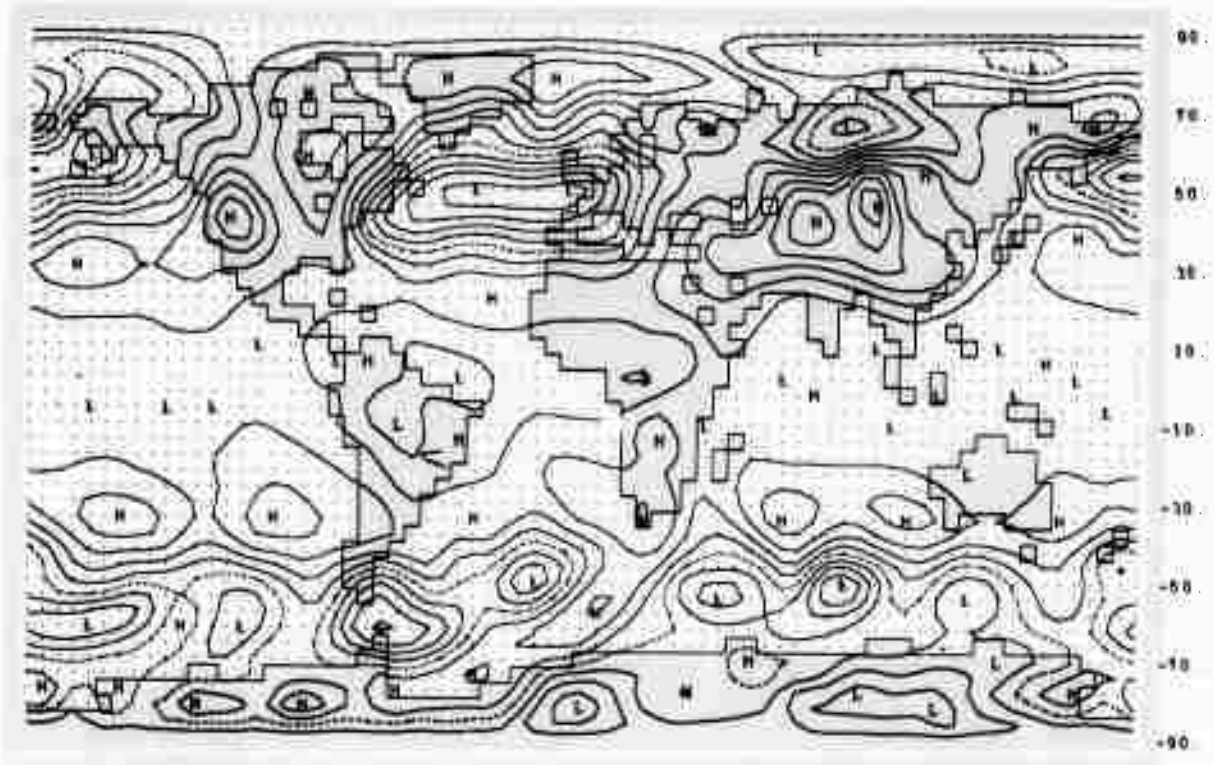


Fig. 4.31 -- Total heat balance at the surface. The dashed line is 0 and the isoline interval is 200 ly day<sup>-1</sup>.

## 2. Surface-Pressure Sequence

To illustrate the typical time behavior of the circulation simulated by the model, a 10-day sequence of the solution for sea-level pressure is presented in Fig. 4.32. These maps are from the same control experiment as those shown in Subsection A.1 above, and constitute a time series starting with Map 1 of Fig. 4.1. These maps show the sea-level pressure isolines at 5-mb intervals, with an additive 1000 mb understood. It is characteristic of the model's solutions that the sea-level pressure distribution maintains a synoptic-like structure as successive cyclone families are formed in the middle latitudes.

DAY 400



DAY 401

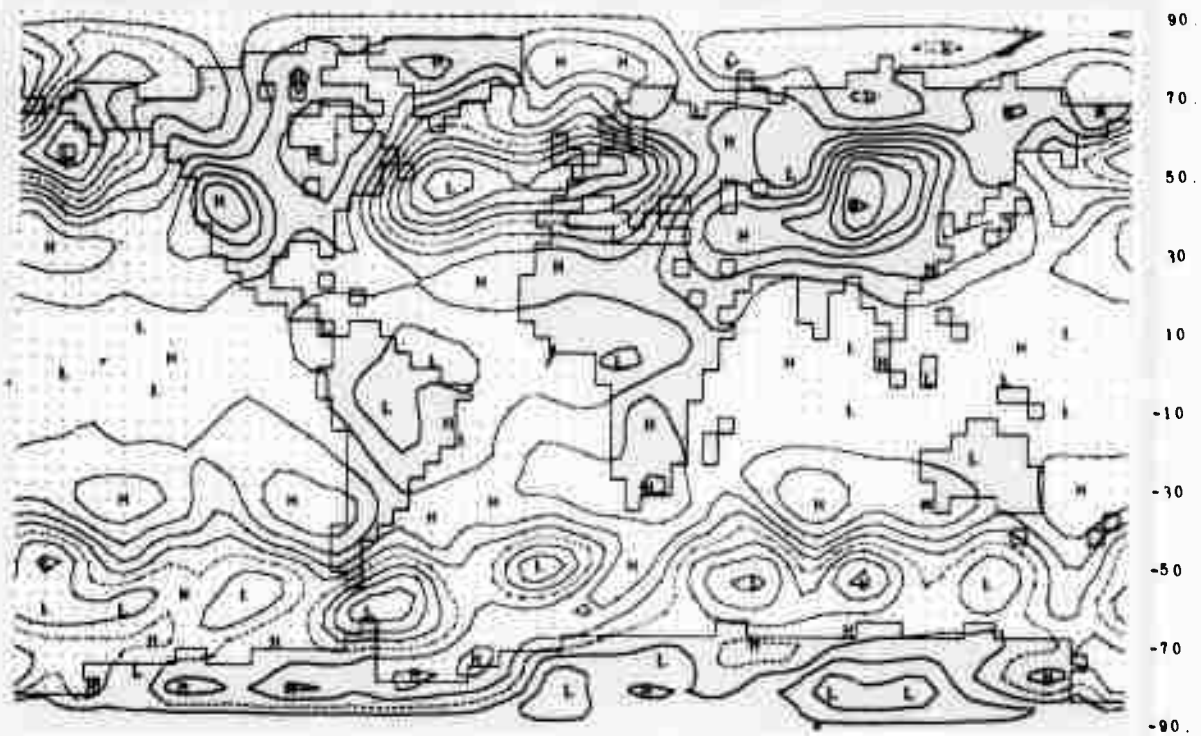
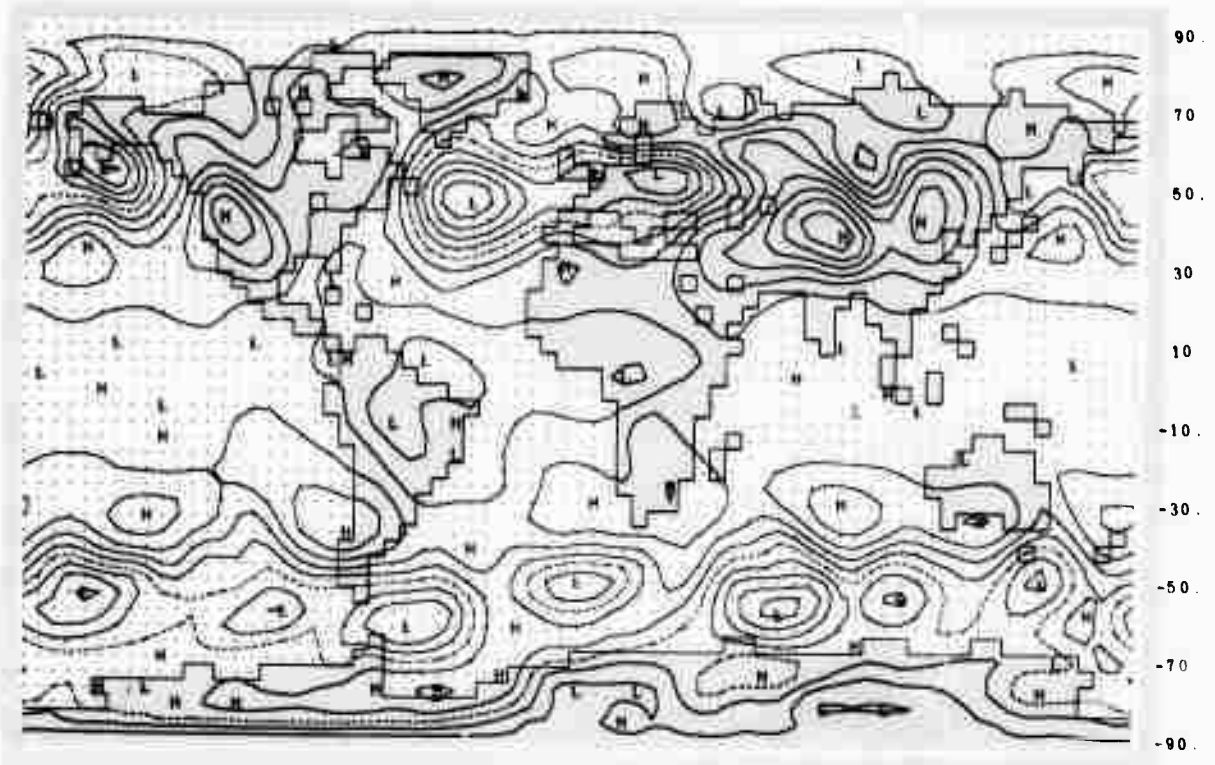


Fig. 4.32 -- Daily sequence of smoothed sea-level pressure. The dashed line is 1000 mb and the isoline interval is 5 mb (see Fig. 4.1).



DAY 402



DAY 403

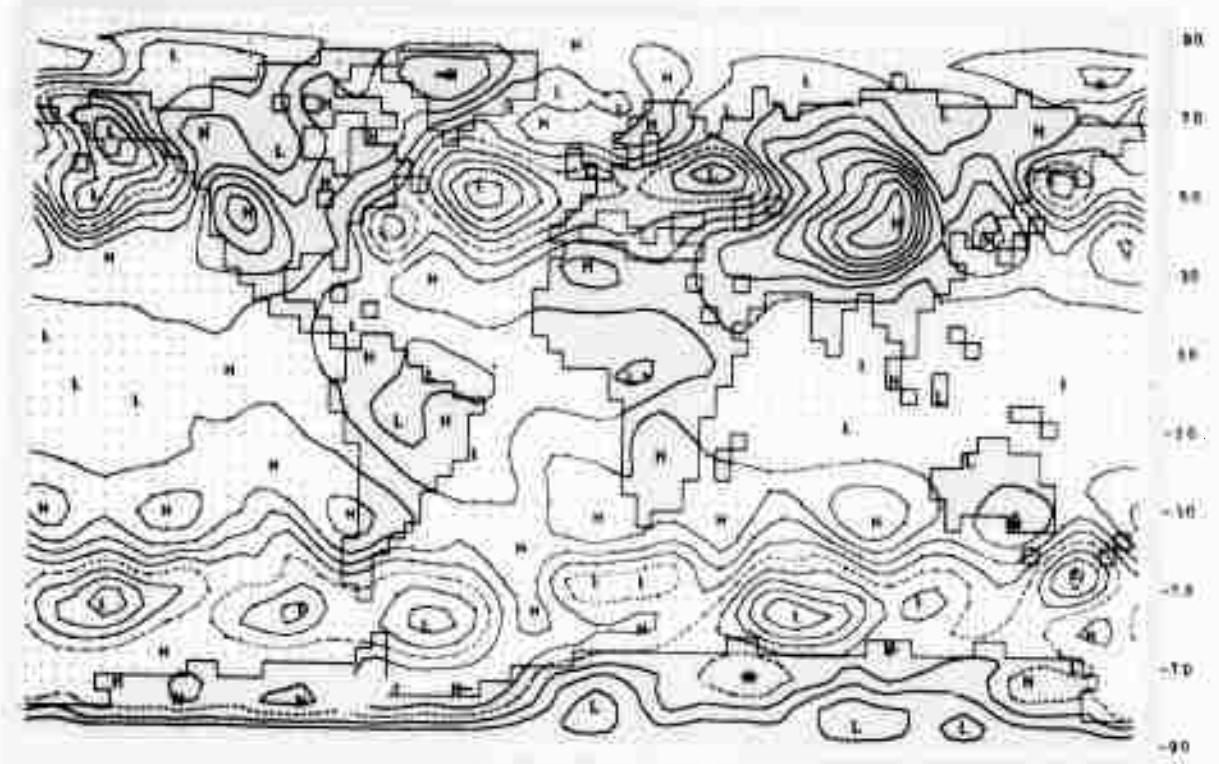
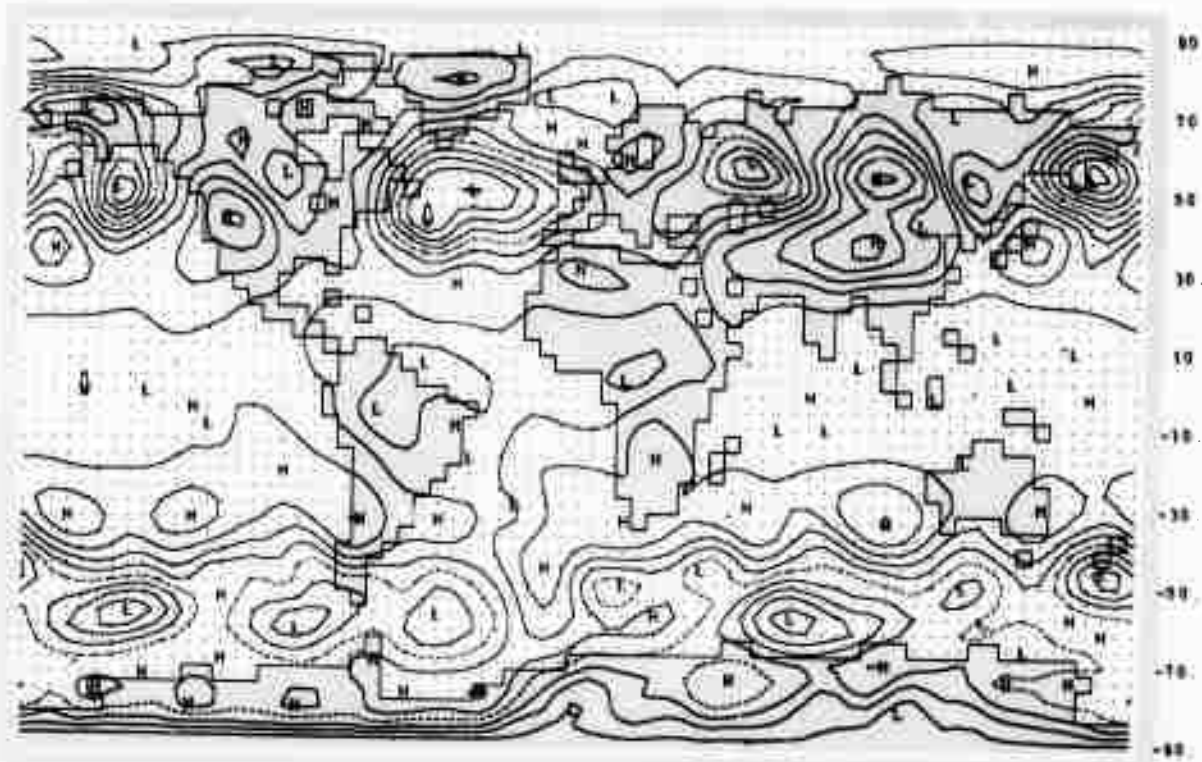


Fig. 4.32 -- Continued.

DAY 404



DAY 405

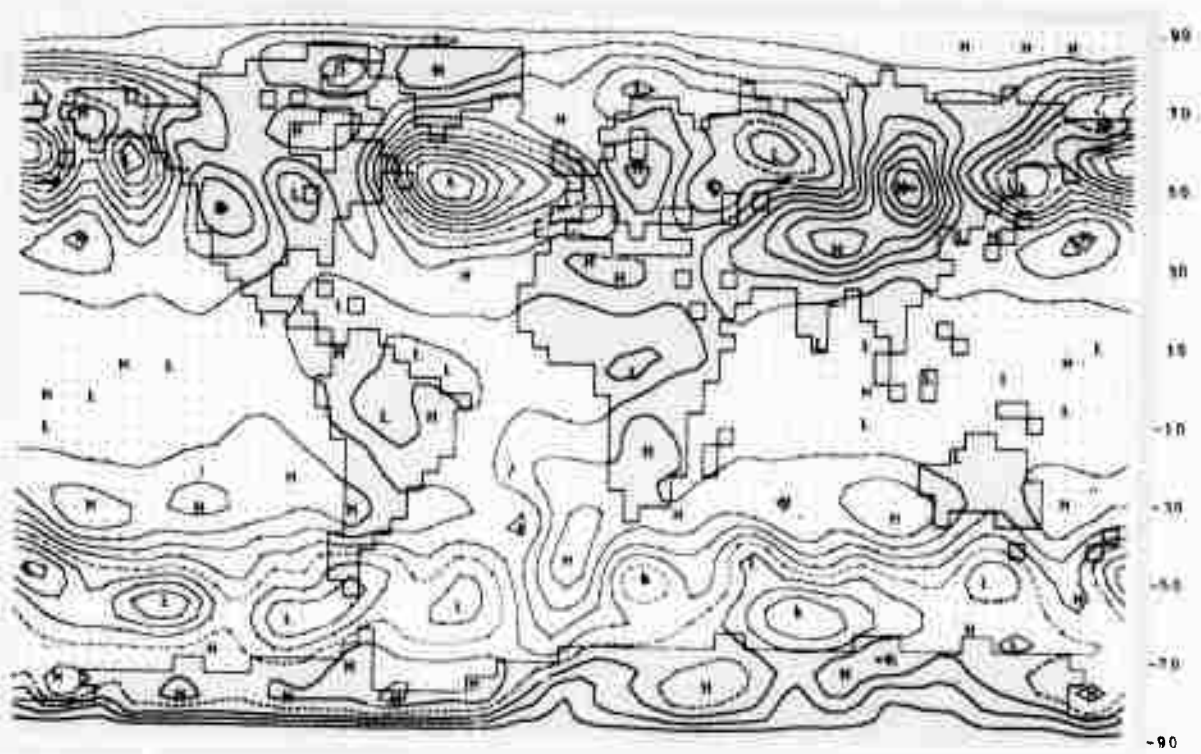
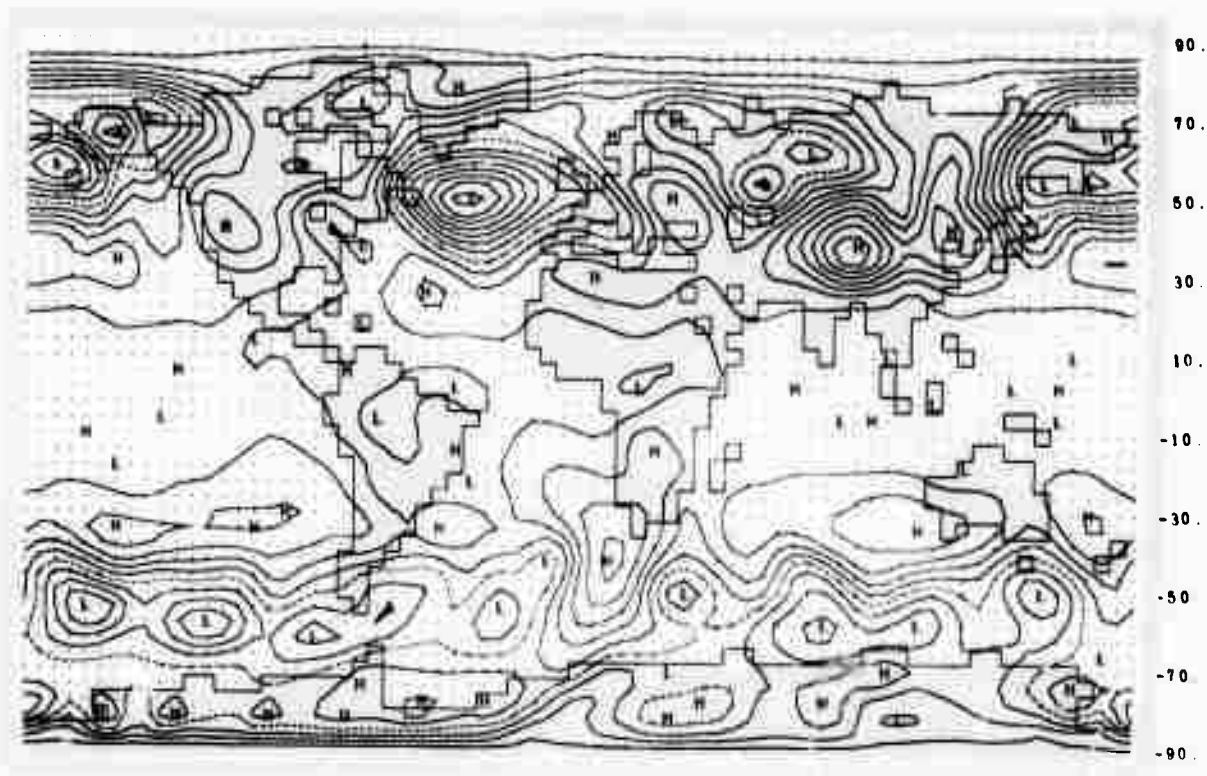


Fig. 4.32 -- Continued.

DAY 406



DAY 407

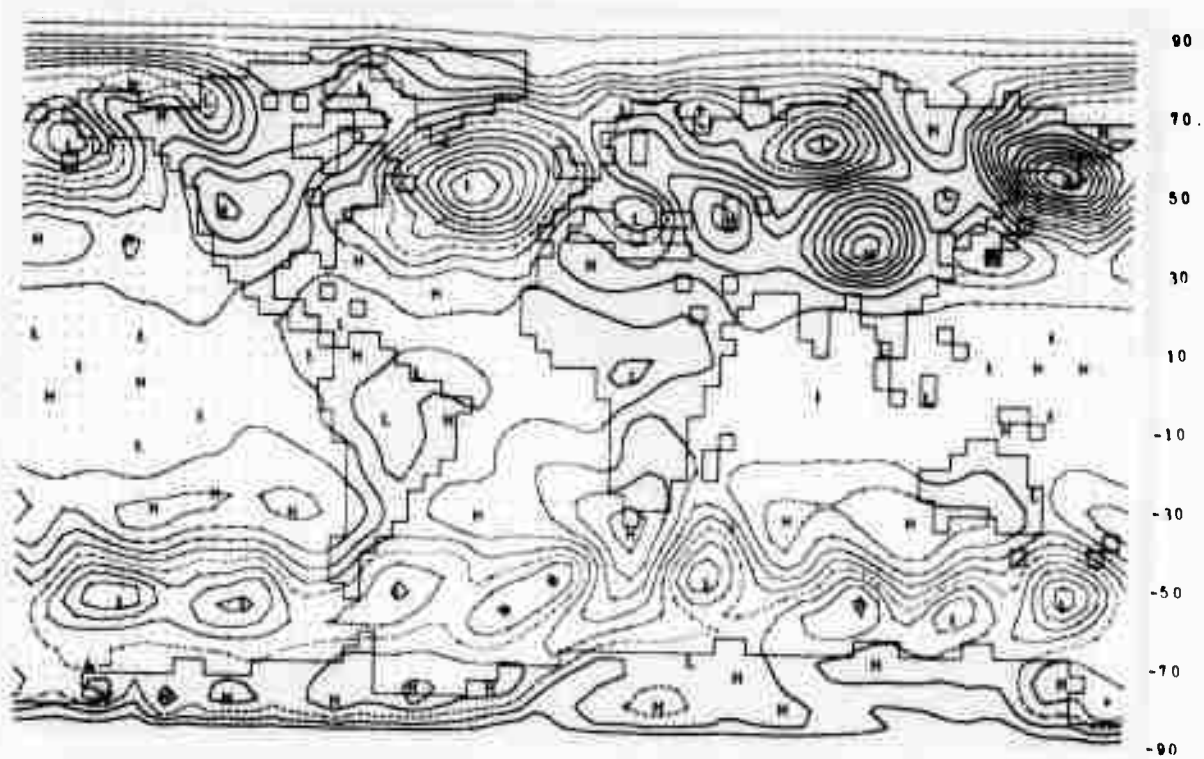
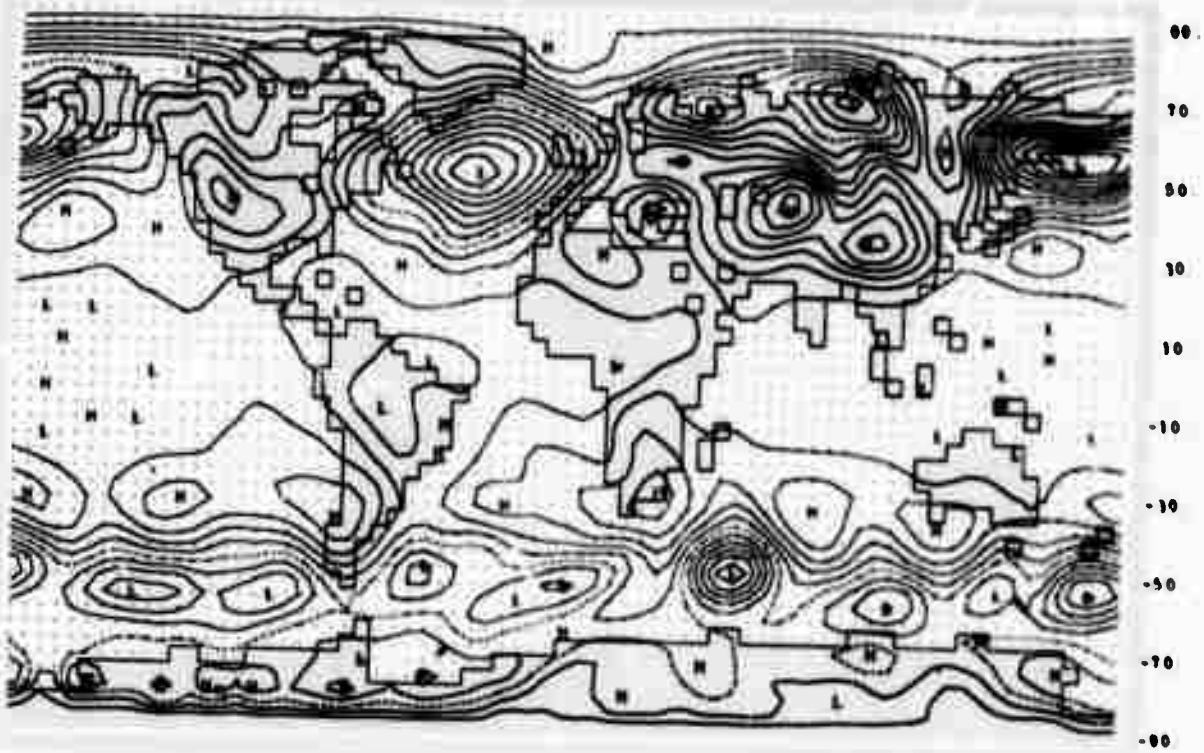


Fig. 4.32 -- Continued.



DAY 408



DAY 409

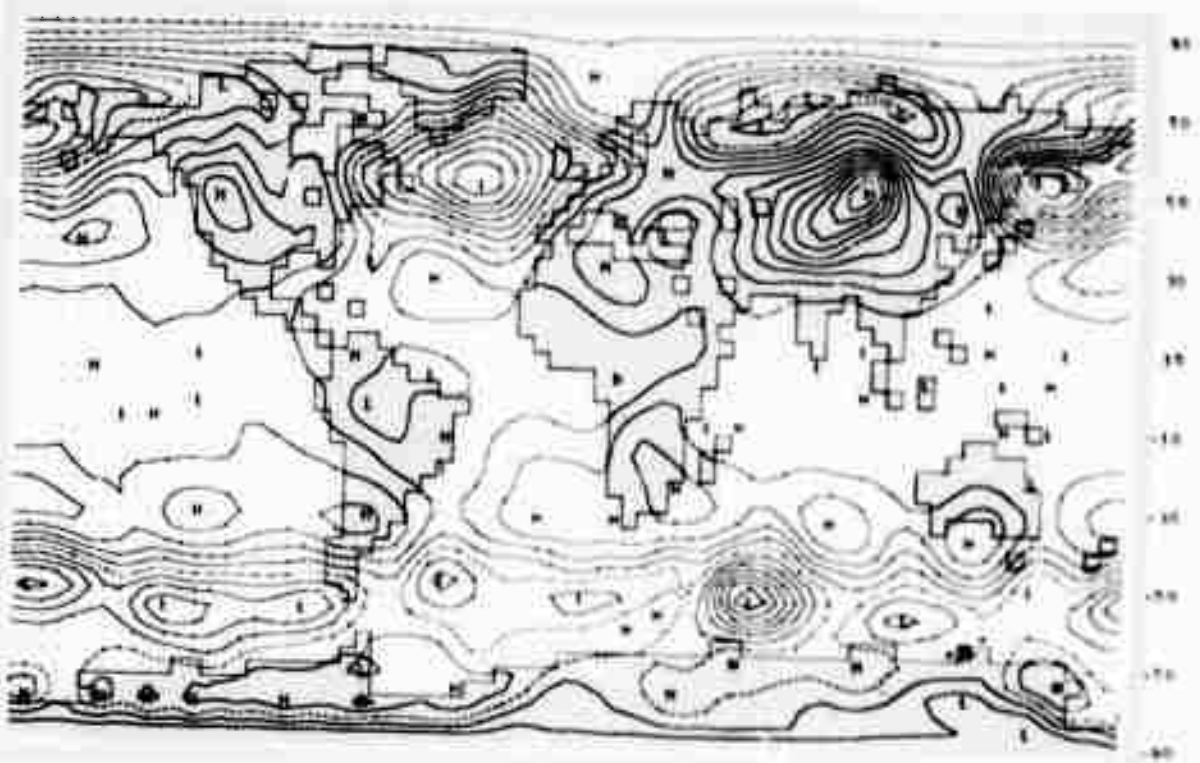


Fig. 4.32 -- Continued.

## V. PHYSICS DICTIONARY

### PURPOSE

This list of terms permits easy entry into the model's physics and its numerical procedures without prior knowledge of specific mathematical or FORTRAN symbols. In this sense it complements the list of symbols and FORTRAN dictionary given in Chapter VIII. This list, of course, is by no means a complete one, but the authors have included those terms commonly associated with the numerical simulation of the general atmospheric circulation. For each term a brief description (and location) of its treatment in the model is given, together with any appropriate symbols, values, units, FORTRAN representations, and program locations.

### LIST OF TERMS

#### Albedo

The albedo of the earth's surface,  $\alpha_g$  (ALS), is assumed constant for two types of surface topography: 0.14 for bare land, 0.07 for ocean. The albedo of ice and of snow-covered land varies from about 0.40 to 0.90 and is dependent upon latitude and time of year (see instructions 10240 to 10410 in the FORTRAN listing), but does not depend in the present version upon the simulated circulation. The albedo of clouds,  $\alpha_c$  (ALAC), used in the treatment of radiation varies between 0.6 and 0.7, depending upon the simulated clouds (see instructions 7620 to 7640 in the FORTRAN listing). The value of the albedo of the cloudless atmosphere for (Rayleigh) scattering,  $\alpha_o$  (ALAO, instruction 10450), is a function of pressure and solar zenith angle, while for an overcast sky,  $\alpha_{ac}$ , it depends upon both  $\alpha_o$  and  $\alpha_c$  (see instructions 10650, 10750, 10880). See Chapter II, Section G, for further details.

#### Boundary Conditions

At the earth's surface ( $\sigma = 1$ ) and at the assumed isobaric tropopause ( $\sigma = 0$ ) the condition  $\dot{\sigma} = d\sigma/dt = 0$  is imposed. This ensures no

motion through the surface  $p = p_s$  at the ground (kinematic boundary condition), and no motion through the surface  $p = p_T$  (free surface condition), where  $p_T$  ( $= 200$  mb) is the assumed tropopause pressure. There are no lateral boundary conditions in the global model, although there are some computational adjustments at the poles (see Chapter III). Over a water surface (ocean or lake) the surface temperature is fixed at a climatological mean value, whereas over a snow or ice surface (sea ice or glacier) the surface ground temperature, although in general calculated by the model, is not allowed to warm above  $0$  deg C.

### Clouds

Clouds are simulated in the model both through large-scale condensation and through convection. The degree of cloudiness affects the short-wave radiation by reflection (with an assumed cloud albedo) and by partial absorption within the cloud by means of a fictitious water-vapor amount  $u_c^*$ . The cloudiness also affects the long-wave radiation balance (see Chapter II and subroutine COMP 3, instructions 9400 to 10230 and 10540 to 11200). The cloudiness parameters CL1, CL2, and CL3 represent: (1) either penetrating or midlevel convection, (2) large-scale condensation, and (3) low-level convection, respectively. These are combined into the total or effective cloudiness measure CL, which is the fraction of sky assumed to be cloud-covered ( $0 \leq CL \leq 1$ ). The measures CL1 and CL3 also depend upon the humidity at level 3. See Chapter II, Subsection F.4, for further details and Figs. 4.27 to 4.29, Chapter IV, for typical distributions.

### Condensation

Large-scale condensation (PREC) occurs mainly as a result of the lifting of saturated air; the model's only atmospheric moisture,  $q_3$ , is at the level  $\sigma = 3/4$  and this is assumed representative of the average moisture in the layer  $\sigma = 1/2$  to  $1$ . Convective condensation (C1, C3, PC1, PC3) is parameterized in both the upper and lower levels, although moisture continues to be carried only at the level 3. Condensation (dew deposit) may also occasionally occur on the surface as

negative evaporation (E4). Since no cloud liquid-water content is carried, condensation is equivalent to precipitation in the model (see subroutine COMP 3, instructions 8620 to 8800, 9140 to 9360). See also Chapter II, Subsections F.2 and F.3, for further details; and Figs. 4.12 and 4.16, Chapter IV, for typical distributions.

### Convection

Low-level convection is simulated under unstable conditions by altering the surface air temperature (level 4) by an amount necessary to restore the vertical lapse rate between levels 3 and 4 to a stable configuration. If the lapse rate between the surface and the upper level 1 is unstable, a penetrating convective heating is introduced in the heat budget of both the upper and lower layer, as well as at the surface, so as to restore stability. See Chapter II, Section F; and subroutine COMP 3, instructions 8700 to 8880, 8960 to 9390, for further details.

### Convective Adjustment

As a result of advective temperature changes and diabatic heating at the levels 1 and 3, the vertical temperature lapse rate may become dry-adiabatically unstable. This is checked in a test for dry-adiabatic instability every 30 minutes, or every 5 time steps (before the heating), in subroutine COMP 3 (instructions 8180 to 8320), wherein the potential temperatures  $\theta_1$  and  $\theta_3$  are both set equal to the value  $(T_1 + T_3)/(p_1^K + p_3^K)$ , if prior to the adjustment  $\theta_3 > \theta_1$ . See Chapter II, Subsection F.1, for further details.

### Coriolis Force

The Coriolis force (per unit mass),  $f = 2\Omega \sin \varphi$ , is computed for each latitude by means of a finite-difference approximation to the equality  $\sin \varphi = -\frac{\partial \cos^2 \varphi / \partial \varphi}{2 \cos \varphi}$ . This is performed in the subroutine MAGFAC (see instructions 14700 to 14750), wherein F(J) is the Coriolis parameter. See Chapter III, Subsection C.5, for further details.

### Diffusion Coefficient

The coefficient of lateral eddy diffusion is set equal to zero in the present version of the model. However, provision has been made for including a diffusion of horizontal momentum in the subroutine COMP 4 (see instructions 12270 to 12680), with horizontal diffusion coefficients dependent upon the local mesh sizes.

### Drag Coefficient

Over the oceans the drag coefficient  $C_D$  is a function of the surface wind speed,  $\vec{V}_s$ , and is given by  $1.0 + 0.07|\vec{V}_s|10^{-3}$  or 0.0025, whichever is smaller. Over land (and ice or snow)  $C_D$  is given by  $0.002 + 0.006(z_4/5000 \text{ m})$ , where  $z_4$  is the height of the surface. This is computed as CD in subroutine COMP 3 (see instructions 7910 to 7980). See Chapter III, Subsection C.10, for further details.

### Evaporation

The surface evaporation rate, E, is locally computed every five time steps over both ocean and land as E4 in the subroutine COMP 3 (see instruction 11240). The evaporation is dependent upon the local surface wind speed and drag coefficient, the local surface air density and temperature, and the low-level vertical moisture gradient. The evaporation distribution is illustrated in Fig. 4.17, Chapter IV. See Chapter II, Subsection F.4, for further details.

### Finite-Difference Grid

The present model's primary or  $\pi$  grid consists of points spaced 5 deg longitude and 4 deg latitude over the globe, and is illustrated by the symbol (o) in Fig. 3.2. At the set of such points including the poles (but not the equator) the variables  $\pi$ , T,  $\phi$ , and q are determined, while at the set of points 4 deg latitude apart including the equator (but not the poles) and displaced eastward 2-1/2 deg longitude relative to the  $\pi$  grid, the horizontal speeds u and v are determined [the u,v grid, illustrated by the symbol (+) in Fig. 3.2]. The

complete grid therefore consists of 6552 distinct data points at each of two levels, with additional information stored for the  $\pi$  grid at the surface. For computational convenience additional subgrids are defined in Chapter III (see Fig. 3.2).

### Friction

The internal frictional force arising from the vertical shear stress of the horizontal wind between levels 1 and 3 is written  $\mu(\vec{V}_1 - \vec{V}_3)(z_1 - z_3)^{-1}(2g/\pi)$ , where  $\mu = 0.44 \text{ mb sec}$  is an empirical shear-stress coefficient. This frictional force is applied with opposite signs in the equations of motion at levels 1 and 3. The frictional force at the earth's surface (which affects level 3 only) is written  $C_D \rho_4 \vec{V}_s (|\vec{V}_s| + G)(2g/\pi)$ , where  $C_D$  is the drag coefficient,  $\vec{V}_s$  the (extrapolated) surface wind, and  $G = 2.0 \text{ m sec}^{-1}$  an empirical correction for gustiness. These frictional forces are computed every fifth time step in subroutine COMP 3 (see instructions 11500 to 11620). See Chapter II, Section E, and Chapter III, Subsection C.10, for further details.

### Geopotential

The geopotential,  $\phi$ , of the sigma surfaces is used in the subroutine COMP 2 to compute a portion of the horizontal pressure gradient force (see instructions 5210 to 5700). The geopotential computation is based upon the assumption that the potential temperature is linear in  $p^k$  space; it is illustrated in Figs. 4.8 and 4.9, Chapter IV.

The geopotential of constant-pressure surfaces may also be calculated for interpretive purposes, as shown in Figs. 4.8a and 4.9a, Chapter IV.

### Grid-Point Separation

The zonal (west/east) distance between grid points,  $\Delta\lambda$ , is equal to 5 deg longitude (FORTRAN symbol DLON), for which the actual distance varies with latitude as given by the map metric  $m$  (FORTRAN symbols DXU, DXP, in Fig. 3.4). The meridional (south/north) distance between grid

points,  $\Delta\varphi$ , is equal to 4 deg latitude (FORTRAN symbol DLAT), with the equivalent distance given by the map metric  $n$  (FORTRAN symbols DYU, DYP in Fig. 3.3). These variables are computed in the subroutine MAGFAC (see instructions 14360 to 14850). See Chapter III, Section B, for further details.

#### Ground Temperature

The temperature of the ground at the earth's surface (FORTRAN symbol TG) is computed in subroutine COMP 3 (instructions 11010 to 11200) as a function of the surface radiation balance (short-wave absorption minus net long-wave emission), evaporation, and vertical sensible heat flux. This is done under the assumption of no heat transfer into the ground (zero heat capacity for bare land, snow-covered land, or ice-covered land). Over an ice-covered ocean the surface temperature is computed as for bare land, except that heat flux through the ice is permitted. Ice- and snow-covered surfaces are not allowed to become warmer than 0 deg C. Over water surfaces the temperature is held at the assigned sea-surface temperature distribution (FORTRAN symbol TG00). See Chapter II, Section G, for further details; and Fig. 4.25, Chapter IV, for a typical distribution.

#### Ground Wetness

The degree of wetness of the ground surface is measured by a dimensionless parameter (FORTRAN symbols WET and GW) varying between 0 and 1. This is computed in subroutine COMP 3 (instructions 11280 to 11390) as a function of the surface-moisture budget (precipitation, evaporation, and runoff). Ice-, snow-, and water-covered surfaces have a ground-wetness parameter equal to 1 (saturation). See Chapter II, Subsection F.7, for further details; and Fig. 4.26, Chapter IV, for a typical distribution.

#### Heat Balance

A net heating or cooling may occur in either the upper or lower layers of the model from the absorption of short-wave (solar) radiation,

net long-wave radiation, the convective heating, and (in the lower layer only) through large-scale condensation and the surface flux of sensible heat. The sum of these effects may be termed the heat balance, which on the long-term average over the global domain should be approximately zero. At the earth's surface (over bare land or snow- or ice-covered land) a heat balance is assumed among the fluxes of short- and long-wave radiation, the upward sensible heat flux, and the latent heat used for surface evaporation. This balance is used to determine the ground temperature, and corresponds to a zero land heat capacity. A similar balance is assumed over ice-covered ocean surfaces, except that heat flux through the ice is permitted (snow and ice temperatures may not exceed 0 deg C). Over water surfaces there is no surface heat balance in the model because the water's surface temperature is fixed. The surface heat balance is illustrated in Fig. 4.31, Chapter IV. See Chapter II, Section G, for further details.

### Heating

Diabatic heating occurs in the upper and lower layers of the model as a result of the radiation (both short- and long-wave) and the convective heating. In the lower layer there is also heating by large-scale condensation (PREC) and by the vertical (turbulent) flux of sensible heat (F4). These heat sources are computed every 5 time steps (= 30 min) in subroutine COMP 3 (instructions 11170 to 11310), and are used to change the temperature at levels 1 and 3. The total heating (in layers), surface sensible heat flux, long-wave heating (in layers), short-wave heating (in layers), surface short-wave absorption, and the surface long-wave cooling are illustrated in Figs. 4.10 and 4.11, 4.18, 4.19 and 4.20, 4.21 and 4.22, 4.23, and 4.30, respectively, of Chapter IV. See Chapter II, Section G, for further details.

### Ice

The distribution of surface ice is prescribed in the present version of the model, and is shown in Figs. 3.13 and 3.14 for land ice and sea ice by the overprinted symbol I. The elevation of the land ice



is also shown in Fig. 3.13, while the sea ice is assumed to be at sea level. These ice locations are identified in the topography input deck (TOPOG) in subroutine INIT 2 by the values  $\leq -10^5$ , with the amount below  $-10^5$  equal to the ice surface's elevation above sea level (in  $10^2$  ft). In the computation of the heat balance over sea ice, the ice is assumed to be 300 cm thick (HICE) and to have a thermal conductivity (CTI) =  $0.005 \text{ ly cm sec}^{-1} \text{ deg}^{-1}$ , and is not allowed to be warmer than 0 deg C (TICE). Except for its albedo (and not being allowed to warm above 0 deg C), land ice is treated in the same manner as bare land with GW = 1.

#### Long-Wave Radiation

The upward long-wave radiative flux is computed at the tropopause (R0), at the level 2 (R2), and at the ground (R4), taking into account the atmospheric emissivity, transmissivity, and the presence of clouds. This is performed every 5 time steps in subroutine COMP 3 (instructions 9750 to 10220, 11040 to 11200). The net fluxes R2 - R0 and R4 - R2 contribute to the change of air temperature at levels 1 and 3, while the surface flux R4 contributes to the change of ground temperature and to the surface heat balance. These fields are illustrated in Figs. 4.19, 4.20, and 4.30 of Chapter IV. See Chapter II, Subsection G.2, for further details.

#### Low-Level Convection

The effect of relatively shallow or low-level convection on the surface temperature and moisture is parameterized in the model in terms of a generalized convection measure. There is no low-level convection unless the lapse rate is unstable between levels 3 and 4 (as measured by the temperature parameters HH4 and HH3S). In addition, the atmosphere must be stable between levels 1 and 3. Under these conditions the surface temperature (T4) and moisture (Q4) are adjusted to simulate low-level convective transports every 5 time steps in subroutine COMP 3 (see instructions 8700 to 8790, 9140 to 9350). See Chapter II, Section F, for further details.

### Middle-Level Convection

This form of convection occurs if the atmosphere is unstable between levels 1 and 3, and alters the heat and moisture distribution at these levels. Midlevel clouds will be created if the level-3 relative humidity exceeds 50 percent. See subroutine COMP 3 (instructions 8810 to 8880) and Chapter II, Section F, for further details.

### Moisture

The mixing ratio (Q3) is computed at the lower level 3 in the model at the points of the  $\pi$  grid in the subroutine COMP 1 (instructions 3520 to 3740), and the moisture sources and sinks due to evaporation and condensation are computed every 5 time steps in subroutine COMP 3 (instructions 8330 to 8450). The upper model level 1 is considered dry, and the moisture advections are such that total moisture is conserved in the absence of sources and sinks. The surface moisture balance is computed in subroutine COMP 3 (instructions 8540 to 8590, 8970 to 9120, 11280 to 11410), and includes the effects of evaporation (E4), precipitation (PREC), ground wetness (GW), and runoff. The moisture distribution is illustrated in the form of the relative humidity at level 3 in Fig. 4.14, Chapter IV, and the total precipitable water is illustrated in Fig. 4.15, Chapter IV. See Chapter II, Section F, and Chapter III, Subsection C.9, for further details.

### Momentum Advection

The horizontal advection of momentum is computed in subroutine COMP 1 (instructions 3750 to 4120) in a way which ensures momentum conservation and the conservation of kinetic energy and the square of relative vorticity (in the absence of sources and sinks). This is accomplished by keeping track of the momentum fluxes (PU, PV, FLUXU, FLUXV) between neighboring u,v-grid cells, and with special adjustment near the poles. The vertical advection of momentum is also computed in subroutine COMP 1 (instructions 4690 to 4860), and represents a momentum exchange between levels 1 and 3 through the large-scale vertical velocity (SD). See Chapter III, Subsections C.3 and C.4, for further details.

### Penetrating Convection

Like low-level convection, penetrating or deep convection is parameterized by a convection measure. For penetrating convection to occur, the atmosphere must be unstable between levels 3 and 4 and between levels 1 and 4, but stable between levels 1 and 3. Under these conditions the temperatures at levels 1 and 3 are changed to reflect the vertical convective heat transport (see subroutine COMP 3, instructions 8700 to 8790, 9140 to 9350) with the surface temperature (T4) and moisture (Q4) also changed every 5 time steps. This convection (PC1, PC3) also contributes to the precipitation, although it is assumed that no moisture is carried to the upper level 1. See Chapter II, Subsection F.3, for further details.

### Potential Temperature

The potential temperature  $\theta = T(p_0/p)^{\kappa}$  (FORTRAN symbol TETA) is computed at various levels in the model for use in vertical stability tests and in the vertical interpolation in  $p^{\kappa}$  space for the temperature and geopotential heights at  $\sigma$  (or  $p$ ) surfaces. Here  $p_0 = 1000$  mb and  $\kappa = 0.286$ .

### Precipitation

The large-scale precipitation rate (PREC) is computed every 5 time steps in the subroutine COMP 3 (instructions 8610 to 8690) as a result of the indicated supersaturation at level 3. The temperature at level 3 is also altered by the corresponding release of latent heat. An additional precipitation rate (CP) is due to middle-level and penetrative convective processes (C1, C3, PC1, PC3), which also result in the latent heating of the upper and lower layers (COMP 3, instructions 9140 to 9320, 11430 to 11480). The large-scale and convective precipitation rates are illustrated in Figs. 4.12 and 4.16, Chapter IV. See Chapter II, Subsections F.2 and F.3, for further details.

### Pressure

The atmospheric pressure (PL) is computed at various levels in the model at the points of the  $\pi$  grid, and is widely used in the numerical integrations (see subroutine COMP 3, instructions 8020 to 8160). The pressure of the earth's surface,  $p_s$ , (FORTRAN symbol P4) is carried as a dependent variable through the parameter  $\pi$  (FORTRAN symbol P) =  $p_s - p_T$ , where  $p_T = 200$  mb is the assumed tropopause pressure. The sea-level pressure (illustrated in Fig. 4.1, Chapter IV) is computed on the basis of an assumed lapse rate of 0.6 deg C/100 m between the surface and sea level. Other pressure parameters used are an average surface pressure (PSF = 984 mb), and a reference pressure (PSL = 1000 mb). The surface pressure tendency (FORTRAN symbol PT) is computed each time step in subroutine COMP 1 (instructions 4130 to 4540) as a result of the solution of the mass-continuity equation.

### Pressure-Gradient Force

The pressure force terms in the equations of horizontal motion are calculated in subroutine COMP 2 (instructions 5210 to 6050) as a combination of the gradients of the geopotential,  $\phi$ , and the surface-pressure parameter,  $\pi$ . These computations use finite differences centered at the velocity points and are performed each time step. See Chapter III, Subsection C.6, for further details.

### Radiation

The net radiative flux of both long- and short-wave radiation is computed for the levels 0, 2, and 4 bounding the upper and lower layers of the model, as well as at the ground. These fluxes depend upon atmospheric moisture (in the lower layer), cloudiness, scattering, reflection (from both the earth's surface and from clouds), the solar zenith angle, and absorption, and are computed every 5 time steps in subroutine COMP 3 (instructions 9750 to 11000). The radiation contributes to the temperature change at levels 1 and 3, as well as to the change of surface temperature. See Chapter II, Section G, for further details.

### Sea-Surface Temperature

The temperature at the sea surface is prescribed in the present version of the model. The data shown in Fig. 3.14, Chapter III, approximate the annual mean sea-surface temperature, and have been used in most applications of the model. Any net energy from the radiation exchange and the fluxes of latent and sensible heat at the ocean surface is absorbed by the sea without changing the surface temperature. The sea-surface temperature is read by subprogram INIT 2 (instructions 16020 to 16530) as part of the topography data (FORTRAN symbol TG00), and may be in either deg C or deg F (but not both).

### Sensible Heat Flux

The (turbulent) flux of sensible heat at the earth's surface (FORTRAN symbol F4) is computed every 5 time steps in subroutine COMP 3 (instruction 11250) as a function of the surface wind speed and the low-level vertical temperature gradient (as measured by the difference between the ground, ocean, or ice temperature and the surface air temperature). This flux is illustrated in Fig. 4.18, Chapter IV, and is seen to be frequently negative, representing a sensible heat flux from the air to the ground. See Chapter II, Subsection G.3, for further details.

### Short-Wave Radiation

The incoming short-wave or solar radiation is partitioned into a portion subject to scattering  $S_O^S$  and a portion subject to absorption  $S_O^A$ . The latter component may be absorbed in each of the two model layers, depending upon the moisture and cloudiness, and the net absorbed short-wave radiation (FORTRAN symbols AS1 and AS3) is determined every fifth time step in subroutine COMP 3 (instructions 10430 to 11000); this is part of the diabatic temperature change at levels 1 and 3, as illustrated in Map 20, Chapter IV. The short-wave radiation reaching the surface is partly reflected (depending upon the albedo), and partly absorbed. The net surface insolation absorbed (FORTRAN symbol S4) is illustrated in Fig. 4.23, Chapter IV, and

contributes to the surface heat balance. See Chapter II, Subsection G.1, for further details.

### Smoothing

There is relatively little explicit smoothing in the present version of the model, although there is considerable averaging in the finite-difference formulations. The subroutine AVRX is used to perform an effective zonal averaging of certain quantities at higher latitudes in subroutines COMP 1 and COMP 2. There is also a 9-point spatial smoothing of the diabatic heating at levels 1 and 3 which is performed in subroutine COMP 3 (instructions 11850 to 12020), and a similar smoothing of the temperature lapse rate in subroutine COMP 4 (instructions 12700 to 12860). See Chapter III, Section D, for further smoothing details, and Subsection C.1 for a discussion of the subroutine AVRX.

### Snow Cover

In the present version of the model the snow cover on the earth's surface is prescribed. In the northern hemisphere, all land surfaces (except ice-covered land) north of the latitude defined by the parameter SNØWN (see instruction 7460 in subroutine COMP 3) are assumed to be covered by snow. The southern boundary of this snow line averages at 60 deg N but varies in time with a period of one year and with an amplitude of 15 deg latitude, with maximum extent on January 25. In the southern hemisphere, a constant snowline SNØWS (see instruction 7470 in subroutine COMP 3) prescribes snow-covered land south of 60 deg S, but this is overridden in the model's present version, because all points south of 60 deg S are either ocean, sea ice, or land ice.

### Solar Constant

The value of the solar constant is taken to be  $2 \text{ ly min}^{-1} = 2880 \text{ ly day}^{-1}$ . This value is modified in subroutine COMP 3 (instruction 7610) to take account of the seasonal variation of the earth/sun

distance in the calculation of the FORTRAN variable S0 (see instruction 15520 in subroutine SDET).

### Temperature

The air temperature (T) is computed each time step in the model for levels 1 and 3 at the points of the  $\pi$  grid, and is widely used in the numerical integration (see instructions 8180 to 8310, subroutine COMP 3). A number of interpolations and extrapolations are made in  $p^k$  space for the temperatures and potential temperatures for use in the radiation and convection calculations. The surface air temperature (T4) is computed as a result of the surface heat and moisture balance (instructions 8960 to 9120, 9340, subroutine COMP 3), while the ground temperature itself (TG) is separately computed. The temperature at levels 1 and 3 is illustrated in Figs. 4.6 and 4.7, Chapter IV, and the surface air temperature is illustrated in Fig. 4.24, Chapter IV.

### Time

Time is measured with respect to hour 0 for midnight at the Greenwich meridian (0 deg longitude), with day 400 corresponding to the 28 January declination of the sun.

### Time Step

In the main integration of the model, the time step  $\Delta t$  is 6 minutes. The friction, heating, evaporation, and condensation source terms, however, are computed only every fifth time step (every 30 minutes) in the subroutine COMP 3. In each step of the 5-step sequence, a preliminary estimate of the new values of the dependent variables is first obtained, then followed by a final estimate in a modified backward-difference scheme. See Chapter III, Section A, for further details, and subroutine STEP (instructions 1850 to 2280). Once each day the total global mass is adjusted in subroutine CMP, and the solar declination and earth/sun distance are recalculated. In the present

version of the model, the output or history tape of the primary dependent variables is written every 6 hours.

### Topography

The topography (TG00) of the earth's surface is prescribed as either water (with a fixed surface temperature), ice (with a maximum temperature of 0 deg C), or land (which may be snow-covered, depending upon the latitude and time of year). The elevation of all land points is prescribed (whether ice-covered, snow-covered, or bare), and is shown in Fig. 3.13, Chapter III; the assigned sea-surface and lake temperatures and ice locations are shown in Fig. 3.14, Chapter III. The topography is read into the program by the subroutine INIT 2, and the land elevation data is decoded in subroutine VPHI4.

### Transmission Function

The transmission function for short-wave radiation (FORTRAN symbol TRSW; see subroutine COMP 3, instructions 10460 to 11000) is given by the empirical expression  $1 - 0.271(x)^{0.303}$ , where (x) is the effective water vapor concentration in a vertical atmospheric column (see subroutine COMP 3, instructions 9750 to 10230). The transmission function for long-wave radiation (FORTRAN symbol TRANS; see subroutine COMP 3, instructions 9910 to 10220) is given by the expression  $[1 + 1.75(x)^{0.416}]^{-1}$ . See Chapter II, Section G, for further details.

### Tropopause

The tropopause in the model is assumed to be always at the pressure  $p_T = 200$  mb (FORTRAN symbol PTR0P), and is used in the definition of the tropospheric  $\sigma$ -coordinate system. At this level the boundary condition  $\dot{\sigma} = 0$  is applied.

### Vertical Velocity

The  $\sigma$ -vertical velocity  $\pi\dot{\sigma} = \dot{S}/2m$  (FORTRAN symbol SD =  $\dot{S}$ ) is computed in the model for the middle level 2 from the equation of



continuity as a result of the net horizontal mass convergence (see subroutine COMP 1, instructions 4320 to 4540). The vertical velocity is used to effect the vertical advection of momentum and temperature, and to determine the large-scale precipitation rate; it is illustrated in Fig. 4.13, Chapter IV. See Chapter III, Subsections C.1, C.2, and C.8, for further details.

#### Wind Velocity

The horizontal zonal and meridional wind speeds (FORTRAN symbols U and V) are computed each time step in the model at the points of the u,v grid, and are widely used in the program. These fields are illustrated in Figs. 4.2 to 4.5 in Chapter IV. In the subroutine COMP 1 a number of spatially averaged speeds and fluxes are defined for use in the horizontal advections of momentum, mass, heat, and moisture. The wind velocity at the earth's surface (US, VS) is found by linear extrapolation in p from levels 1 and 3 (see subroutine COMP 3, instructions 7490 to 7570), and is used in the determination of the surface friction, evaporation, and sensible heat flux. See Chapter III, Section C, for further details.

## VI. LIST OF SYMBOLS

### PURPOSE

In order to provide a complement to the physics dictionary presented in Chapter V, a comprehensive alphabetical listing and identification of all the symbols used in the discussion of the model's physics and numerics is given here. For each symbol a brief identification, typical value, units, and FORTRAN symbol (if any) is given. Those symbols which occur at more than one level in the model (as designated by the subscripts 1, 2, 3, or 4) are listed following the primary variable. *Not* separately listed are those symbols which occur with the superscripts  $\tau$  or  $n$  (denoting evaluation at time steps), those symbols which occur with the subscripts  $i$  and/or  $j$ , those symbols with various combinations of numerical subscripts (denoting grid-point locations), or those symbols representing a local specialization of a previously defined symbol. In general, symbols which occur only in FORTRAN notation are also not listed here (see Chapter VIII).

SYMBOL LIST

SYMBOL <sup>1</sup>	MEANING	UNITS (and value for constants)	FORTTRAN SYMBOL
$\alpha$ $\alpha_1$ $\alpha_3$	specific volume	$\text{cm}^3 \text{g}^{-1}$	--
$\alpha_{ac}$	albedo of cloudy atmosphere	--	ALAC
$\alpha_c$	cloud albedo (subscripted by cloud type)	--	$\left\{ \begin{array}{l} \text{ALC1} \\ \text{ALC2} \\ \text{ALC3} \end{array} \right.$
$\alpha_g$	albedo of earth's surface	--	ALS
$\alpha_o$	albedo of clear atmosphere	--	ALAO
$\beta$	vertical shear stress parameter	$0.13 \text{ mb}^2 \text{sec m}^{-1}$	--
$\Gamma$	surface sensible heat flux	$1 \text{ y day}^{-1}$	F4
$\Gamma_h$	surface flux of static energy	$1 \text{ y sec}^{-1}$	--
$\gamma$	temperature lapse rate near surface	$0.6 \text{ deg/100 m}$	--
$\gamma$ $\gamma_1$ $\gamma_3$ $\gamma_g$	latent heating parameter $= Lq_s (c_p T^2)^{-1} 5418 \text{ deg}$	--	GAM
$\zeta$	sun's zenith angle	radians	$\text{COSZ}$ $(= \cos \zeta)$
$\eta$	entrainment factor	--	ETA
$\theta$ $\theta_1$ $\theta_2$ $\theta_3$	potential temperature	deg K	TETA

<sup>1</sup>The multiple listing is for symbols occurring with the subscripts 1, 2, 3, or 4; these denote evaluation at the respective model levels  $\sigma = 1/4, 1/2, 3/4, \text{ or } 1$  (surface). The subscripts g and o also sometimes denote the ground or surface level.

SYMBOL	MEANING	UNITS (and value for constants)	FORTRAN SYMBOL
$\bar{\theta}$	an average potential temperature	deg K	--
$\theta_d$	partial potential temperature	deg K	--
$\theta_E$	equivalent potential temperature	deg K	--
$\kappa$	thermodynamic ratio $R/c_p$	0.286	KAPA
$\lambda$	longitude, positive eastward from Greenwich	radians	--
$\Delta\lambda$	longitudinal spacing between grid points	$\pi/36$ radians (= 5 deg)	DLØN
$\mu$	vertical shear stress parameter	0.44 mb sec	--
$\Pi$	pressure area weighting = $\pi m$	$m^2 mb$	FD(J,I)
$\Pi^u$	local four-point average of $\Pi$ centered on u,v grid points	$m^2 mb$	FDU(J,I)
$\pi$	(1) surface pressure parameter = $p_s - p_T$ (2) constant	mb 3.14159	SP,P(J,I) PI
$\dot{\pi}$	surface pressure change = $\frac{dp_s}{dt}$	mb sec <sup>-1</sup>	PT
$\pi_s$	standard value of $\pi$	800 mb	PM
$\pi^u$	local four-point average of $\pi$ centered on u,v grid points	mb	--
$\rho$ $\rho_4$ }	air density	g cm <sup>-3</sup>	RHØ, RØ4

SYMBOL	MEANING	UNITS (and value for constants)	FORTTRAN SYMBOL
$\rho_w$	water density	$1 \text{ g cm}^{-3}$	--
$\sigma$	Stefan-Boltzman constant	$1.171 \times 10^{-7}$ $\text{ly day}^{-1} \text{deg}^{-4}$	STBØ
$\sigma$ $\sigma_1$ $\sigma_3$	vertical coordinate $= (p - p_T)/(p_s - p_T)$	--	SIG
$\dot{\sigma}$ $\dot{\sigma}_2$	sigma vertical velocity = $d\sigma/dt$	$\text{sec}^{-1}$	SD
$\tau$	time-step index	--	TAU
$\tau$ $\tau_1$ $\tau_2$	intermediate variables in penetrating convection	deg K	TEMP
$\tau_r$	relaxation time for cumulus convection	3600 sec	TCNV
$\tau(u^*)$	long-wave transmission function $= [1 + 1.75(u^*)^{0.416}]^{-1}$	--	TRANS(X)
$\bar{\tau}_A$ $\bar{\tau}_B$	long-wave transmission above and below a given level	--	--
$\phi$ $\phi_1$ $\phi_3$	geopotential of sigma surface	$\text{m}^2 \text{sec}^{-2}$	PHI
$\phi_4$	geopotential of $\sigma = 4$ surface	$\text{m}^2 \text{sec}^{-2}$	VPHI4

SYMBOL	MEANING	UNITS (and value for constants)	FORTTRAN SYMBOL
$\varphi$	latitude, positive northward from equator	radians	LAT(J)
$\Delta\varphi$	latitudinal spacing between grid points	$\pi/45$ radians (= 4 deg)	DLAT
$\psi$	arbitrary variable	--	--
$\Omega$	earth's rotation rate	$2\pi$ radians/day	RØT
$\omega$	pressure vertical velocity = $dp/dt$	--	--
A	absorbed short-wave radiation	ly day <sup>-1</sup>	--
$\left. \begin{matrix} A_1 \\ A_3 \end{matrix} \right\}$	absorbed short-wave radiation in upper and lower layers	ly day <sup>-1</sup>	AS1, AS3
$A_v$	eddy diffusion coefficient	m <sup>2</sup> sec <sup>-1</sup>	--
$\vec{A}$	arbitrary vector, whose latitu- dinal and longitudinal com- ponents are $A_\varphi$ and $A_\lambda$	--	--
$A_e$	saturation vapor pressure constant	21.656	--
$A(u^*, z)$	short-wave absorption function = $0.271(u^* \cos \zeta)^{0.303}$	--	TRSW(X)
$A_\psi$	general representation for advection terms	--	--
a	earth's radius	$6.3750 \times 10^6$ m	RAD
B	conduction coefficient for ice	ly day <sup>-1</sup> deg <sup>-1</sup>	--
$\tilde{B}$	generalized conduction coefficient	ly day <sup>-1</sup> deg <sup>-1</sup>	TEM
$B_e$	saturation vapor pressure constant	5418 deg	--
C	condensation rate	g cm <sup>-2</sup> sec <sup>-1</sup>	--

SYMBOL	MEANING	UNITS (and value for constants)	FORTTRAN SYMBOL
$C_1$	ground temperature correction terms in long-wave radiation	ly day <sup>-1</sup>	--
$C_D$	surface drag coefficient	--	CD
$C_r$	sensible and latent heat flux parameter	ly day <sup>-1</sup> deg <sup>-1</sup>	CSEN
CL	cloudiness measure	--	CL
CLAT	degrees poleward of snowline	deg latitude	CLAT
CONV	horizontal mass convergence	m <sup>2</sup> mb sec <sup>-1</sup>	CONV
$c_p$	dry air specific heat at constant pressure	0.24 cal g <sup>-1</sup> deg <sup>-1</sup>	--
$D_\psi$	general representation for non- source terms	--	--
$D_\pi$	general representation for mass advection terms	--	--
E	surface evaporation rate	g cm <sup>-2</sup> sec <sup>-1</sup>	E4
$e_s$	saturation vapor pressure	cb	ES, EG
F	modified Coriolis parameter = mmf - udm/dy	m <sup>2</sup> sec <sup>-1</sup>	FD(J,I)
$\vec{F}$	horizontal vector frictional force (per unit mass)	--	--
$\left. \begin{matrix} F^x \\ F_1^x \\ F_3^x \end{matrix} \right\}$	eastward component of frictional force	--	--
$\left. \begin{matrix} F^y \\ F_1^y \\ F_3^y \end{matrix} \right\}$	northward component of frictional force	--	--

SYMBOL	MEANING	UNITS (and value for constants)	FORTTRAN SYMBOL
$F_4$	upward sensible heat flux from surface	ly day <sup>-1</sup>	F4
$F_H$	vertical heat flux at surface	ly day <sup>-1</sup>	--
$f$	Coriolis parameter = $2\Omega \sin \varphi$	sec <sup>-1</sup>	F(J)
$G$	gustiness correction for surface wind	2 m sec <sup>-1</sup>	G
GW	ground wetness	--	GW
GWM	maximum ground water	30 g cm <sup>-2</sup>	GWM
$g$	gravity	9.81 m sec <sup>-2</sup>	GRAV
$h/c_p$	static energy	deg K	--
$h_3/c_p$	static energy at level 3	deg K	HH3
$h_4/c_p$	static energy at level 4	deg K	{ HH4 HH4P
$\tilde{h}_4/c_p$	intermediate stability parameter	deg K	HH4
$\dot{H}$	diabatic heating rate (per unit mass)	cal g <sup>-1</sup> sec <sup>-1</sup>	--
$H_1$	diabatic temperature change (over $5\Delta t$ ) in layer	deg	H1
$H_3$	diabatic temperature change (over $5\Delta t$ ) in layer	deg	H3
$\bar{H}$	average of $H_1, H_3$	deg	H
$H_E$	surface latent heat flux	ly day <sup>-1</sup>	--



SYMBOL	MEANING	UNITS (and value for constants)	FORTTRAN SYMBOL
$h^*/c_p$	stability parameter	deg K	--
$h_1^*/c_p$	stability parameter at level 1	deg K	HH1S
$h_3^*/c_p$	stability parameter at level 3	deg K	HH3S
I	maximum value of i	72	IM
i	zonal grid-point index	--	I
J	maximum value of j	46	JM
j	meridional grid-point index	--	J
K	moisture parameter	--	VAK
$\vec{k}$	vertical unit vector	--	--
L	latent heat of condensation	580 cal g <sup>-1</sup>	--
$\ell$	level index = 1 at $\sigma_1$ , = 3 at $\sigma_3$	--	L
LR	nominal lapse rate = $(\theta_1 - \theta_3)(p_2/p_o)^K$	deg K	--
$\left. \begin{matrix} M \\ M_b \end{matrix} \right\}$	vertical mass flux in cloud	g cm <sup>-2</sup> sec <sup>-1</sup>	--
$M_w/M_d$	ratio of the molecular weight of water vapor to dry air	0.622	--
m	map metric or zonal distance between grid points = $a\Delta\lambda \cos \varphi$	m	$\left\{ \begin{matrix} DXU \\ DXP \end{matrix} \right.$
n	(1) map metric or meridional distance between grid points = $a\Delta\varphi$ (2) arbitrary time step	m --	$\left\{ \begin{matrix} DYU \\ DYP \end{matrix} \right.$ --

SYMBOL	MEANING	UNITS (and value for constants)	FORTTRAN SYMBOL
$P$	(1) pressure (2) polar grid-point index	mb --	PL --
$P_1$			
$P_3$			
$P_o$	reference pressure	1000 mb	PSL
$P_{CM}$	precipitation rate from middle-level convection	mm day <sup>-1</sup>	--
$P_{CP}$	precipitation rate from penetrating convection	mm day <sup>-1</sup>	--
$P_{LS}$	large-scale precipitation rate	mm day <sup>-1</sup>	--
$P_s$	surface pressure	mb	P4
$P_T$	tropopause pressure	200 mb	PTRØP
$\Delta p_c$	cloud pressure thickness	mb	--
$\Delta p_m$			
$\dot{Q}$	rate of moisture addition (per unit mass)	--	--
$q$	mixing ratio	--	--
$q_3$	mixing ratio at level 3	--	$\left\{ \begin{array}{l} Q3 \\ Q3R \\ Q3RB \end{array} \right.$
$q_4$	mixing ratio at level 4	--	
$q_g$	mixing ratio at ground	--	
$\Delta q_3$	mixing ratio change (at level 3)	--	Q4 QG --

SYMBOL	MEANING	UNITS (and value for constants)	FORTTRAN SYMBOL
$q_s$	saturated mixing ratio	--	QS
$q_{se}$	effective ground saturation mixing ratio	--	--
R	dry air specific gas constant	$287 \text{ m}^2 \text{ deg}^{-1} \text{ sec}^{-2}$	RGAS
$R_\psi$	general representation for non- advective, non-source terms $= D_\psi - A_\psi$	--	--
$R'_n$	clear sky long-wave radiation at level n	$1 \text{ y day}^{-1}$	$\left\{ \begin{array}{l} R00 \\ R20 \\ R40 \end{array} \right.$
$R''_n$	overcast sky long-wave radiation at level n	$1 \text{ y day}^{-1}$	$\left\{ \begin{array}{l} R0C \\ R2C \\ R4C \end{array} \right.$
$\tilde{R}_n$	weighted sum of $R'_n, R''_n$	$1 \text{ y day}^{-1}$	$\left\{ \begin{array}{l} R0 \\ R2 \\ R4 \end{array} \right.$
$R0 \left\{ \begin{array}{l} R_0 \end{array} \right.$	upward long-wave radiation flux at level 0 ( $\sigma = 0$ )	$1 \text{ y day}^{-1}$	R0
$R2 \left\{ \begin{array}{l} R_2 \end{array} \right.$	upward long-wave radiation flux at level 2	$1 \text{ y day}^{-1}$	R2
$R4 \left\{ \begin{array}{l} R_4 \end{array} \right.$	upward long-wave radiation flux at level 4 (surface)	$1 \text{ y day}^{-1}$	R4
$RH_3 \left\{ \begin{array}{l} RH_4 \end{array} \right.$	relative humidity (scaled 0 to 1)	--	RH
S	dry static energy	cal g	--
$\dot{S}$	vertical velocity measure $= 2\pi\pi\dot{\sigma}_2$	$\text{m}^2 \text{ mb sec}^{-1}$	SD(J,I)

SYMBOL	MEANING	UNITS (and value for constants)	FORTTRAN SYMBOL
$(S_1^A)'$	flux of $S_0^A$ at level 1 in clear sky	ly day <sup>-1</sup>	--
$(S_1^A)''$	flux of $S_0^A$ at level 1 in overcast sky	ly day <sup>-1</sup>	--
$(S_{CT1}^A)''$	flux of $S_0^A$ reflected from top of cloud type 1	ly day <sup>-1</sup>	--
$\dot{S}^u$	local four-point average of $\dot{S}$ centered on u,v grid points	m <sup>2</sup> mb sec <sup>-1</sup>	SDU
$S_0$	solar constant (after modification for earth-sun distance)	~2880 ly day <sup>-1</sup>	SØ
$S_0^s$	solar radiation subject to scattering	ly day <sup>-1</sup>	SS
$S_0^A$	solar radiation subject to absorption	ly day <sup>-1</sup>	SA
$S_g$	total solar radiation absorbed at ground	ly day <sup>-1</sup>	S4
$S_g^s$	flux of $S_0^s$ absorbed by ground	ly day <sup>-1</sup>	--
$S_g^A$	flux of $S_0^A$ absorbed by ground	ly day <sup>-1</sup>	--
$S_\psi$	general representation for source terms	--	--
$S_4$	short-wave radiation absorbed at the surface	ly day <sup>-1</sup>	S4
$\left. \begin{matrix} T \\ T_1 \\ T_3 \end{matrix} \right\}$	temperature	deg K	T

SYMBOL	MEANING	UNITS (and value for constants)	FORTTRAN SYMBOL
$T_o$	melting point of ice	273.1 deg K	TICE
$T_0$	tropopause temperature	deg K	TTRØP
$T_4$ ) $T_4$ )	air temperature at level 4 (surface)	deg K	T4
$T_{c1}$ ) $T_{c3}$ )	air temperature in cloud	deg K	--
$\Delta T_1$ ) $\Delta T_3$ )	temperature change (of layer)	deg	--
$(\Delta T_1)_{CM}$ ) $(\Delta T_3)_{CM}$ )	temperature change due to middle- level convection.	deg	--
$(\Delta T_1)_{CP}$ ) $(\Delta T_3)_{CP}$ )	temperature change due to penetrating convection	deg	--
$(\Delta T_3)_{LS}$	level-3 temperature change due to large-scale condensation (= $PREC \cdot L/c_p$ )	deg	--
$T_g$	ground temperature	deg K	{ TG GT(J,I)
$T_{gr}$	revised ground temperature	deg K	{ TGR GT(J,I)
$T_T$	tropopause temperature	deg K	TTRØP
$T^u$	local four-point average temperature centered on u,v-grid points	deg K	--
$\bar{T}$	an average temperature	deg K	--

SYMBOL	MEANING	UNITS (and value for constants)	FORTRAN SYMBOL
TD	lapse rate measure $= (T_3 - T_1)/2\pi$	deg mb <sup>-1</sup>	TD
t	time	sec, min, hr, or days	--
$\Delta t$	time step	6 min	DTM
U	west/east advective flux	m <sup>2</sup> mb sec <sup>-1</sup>	--
$\tilde{U}$	southwest/northeast advective flux	m <sup>2</sup> mb sec <sup>-1</sup>	--
$\left. \begin{matrix} u \\ u_1 \\ u_3 \\ u_4 \end{matrix} \right\}$	zonal (eastward) wind speed	m sec <sup>-1</sup>	U
$\left. \begin{matrix} u^* \\ u_n^* \end{matrix} \right\}$	effective water vapor content in column (to level n)	g cm <sup>-2</sup>	{ EFV EFVT
$u_\infty^*$	effective water vapor content in column (entire atmosphere)	g cm <sup>-2</sup>	EFV0
$\left. \begin{matrix} u^* \\ u_1^* \\ u_3^* \\ u_4^* \end{matrix} \right\}$	zonal mass flux = $n\pi u$	m <sup>2</sup> mb sec <sup>-1</sup>	PU(J,I)
$\left. \begin{matrix} u_c^* \\ u_{c1}^* \\ u_{c2}^* \end{matrix} \right\}$	cloud water vapor equivalent	65.3 g cm <sup>-2</sup>	{ EFVC1 EFVC2

SYMBOL	MEANING	UNITS (and value for constants)	FORTTRAN SYMBOL
$u_{c_3}^*$	cloud water vapor equivalent	$7.6 \text{ g cm}^{-2}$	EFVC3
$V$	south/north advective flux	$\text{m}^2 \text{ mb sec}^{-1}$	--
$\tilde{V}$	southeast/northwest advective flux	$\text{m}^2 \text{ mb sec}^{-1}$	--
$\vec{V}$ $\vec{V}_1$ $\vec{V}_2$ $\vec{V}_3$ $\vec{V}_4$	horizontal velocity vector	$\text{m sec}^{-1}$	--
$\vec{V}_s$			
$ \vec{V}_s ^\pi$	local four-point root-mean-square surface wind speed centered at $\pi$ points	$\text{m sec}^{-1}$	WMAG
$v$ $v_1$ $v_3$	meridional (northward) wind speed	$\text{m sec}^{-1}$	V
$v_1^*$ $v_3^*$ $v_4^*$			
	meridional mass flux = $m\pi v$	$\text{m}^2 \text{ mb sec}^{-1}$	PV(J,I)
W	surface wind speed with gustiness correction	$\text{m sec}^{-1}$	WINDF

SYMBOL	MEANING	UNITS (and value for constants)	FORTRAN SYMBOL
x	eastward coordinate (on rectangular projection)	--	--
y	northward coordinate (on rectangular projection)	--	--
$\left. \begin{array}{l} z \\ z_1 \\ z_3 \\ z_4 \end{array} \right\}$	height of sigma surface	m	ZZZ
$\Delta z$	standard value of $z_1 - z_3$	5400 m	--
( $\wedge$ )	designation for preliminary estimate in time integration	--	--
( $\sim$ )	designation for provisional value prior to incorporation of source terms in time integration	--	--
( $\bar{\phantom{x}}$ )	a smoothing operator denoting a horizontally averaged value	--	--
$\overline{(\phantom{x})}^{N_0}$	an operator denoting the three- point longitudinal smoothing routine in AVRX(K), which is automatically applied $N_0$ times	--	--



## VII. THE FORTRAN PROGRAM

A listing of the computer program actually used in the numerical simulations is perhaps the most important part of the documentation. In the FORTRAN program listing given in Section A below the sequential numbering of all cards in the program deck is reproduced on the right-hand side of the listing to permit easy identification of specific instructions. Following the listing of the integration program and the common block, the program listing for the map routines is presented in Section B with a separate instruction card numbering.

### A. INTEGRATION PROGRAM LISTING

#### 1. Subprograms

The integration program itself is divided into a main or control routine and a number of subroutines. In the order of their appearance in the program, these subroutines (and an indication of their functions and initial program instruction numbers) follow:

COMMON -- lists variables' common and equivalence assignments  
CONTROL -- controls program execution (0120)  
OUTAPE -- reads and writes history tape (0800)  
GMP -- calculates global average surface pressure, and adjusts pressure for mass conservation (1250)  
VPHI4 -- decodes land elevation (1510)  
IPK -- packs data for output (1610)  
KEY -- logical key control (1770)  
STEP -- controls sequence of time steps, and readies data for execution of subroutines COMP 1, COMP 2, COMP 3, and COMP 4 (1850)  
COMP 1 -- calculates mass flux and convergence; horizontal advection of momentum, heat, and moisture; vertical advection of momentum and heat (2290)  
COMP 2 -- calculates Coriolis and pressure-gradient forces (4880)  
AVRX -- performs zonal smoothing (6780)  
COMP 3 -- calculates radiative heating, convection, precipitation, surface and ground temperature, surface evaporation and sensible heat flux, surface friction; calculates selected data for output (7070)

- COMP 4 -- calculates diffusion of momentum (suppressed in the present version); performs areal smoothing of the temperature lapse rate (12040)
- INPUT -- reads input data and controls generation of selected constants (12880)
- MAGFAC -- calculates map scale factors and Coriolis parameter (14350)
- INSDET -- adjusts day, month, and seasonal sun position
- SDET -- calculates solar zenith angle and related parameters (15190)
- INIT 1 -- prepares for cold-start initial conditions (inoperative in the present version) (15620)
- INIT 2 -- reads and encodes surface topography data (sea-surface temperature and land elevation) (15770)

## 2. Guide to the Main Computational Subroutines

The bulk of the computations involved in the solution of the main dynamical equations of the model, Eqs. (2.27) to (2.35), are performed in the subroutines COMP 1, COMP 2, COMP 3, and COMP 4. An outline of these calculations is given below in the sequence performed each time step in the program by the subroutines COMP 1 and COMP 2, followed by an outline for subroutines COMP 3 and COMP 4 which are performed every five time steps. The initial instruction location is cited for each major program subdivision.

Calculation	Initial Instruction
<u>COMP 1</u>	
Formation of area-pressure-weighted variables	2540
Horizontal mass flux	2710
Zonal smoothing (AVRX)	2830
Horizontal polar mass flux	2970
Horizontal temperature advection	3260
Horizontal moisture advection	3390
Horizontal momentum advection	3770
Continuity equation (vertical velocity and surface pressure tendency)	4130

Calculation	Initial Instruction
<u>COMP 1</u>	
Vertical temperature advection	4560
Vertical momentum advection	4690
<u>COMP 2</u>	
Coriolis force	5010
Pressure-gradient force	5220
Zonal smoothing (AVRX)	5970
Thermodynamic energy conversion	6070
Zonal smoothing (AVRX)	6210
Polar adjustment	6410
Return to unweighted variables	6580
<u>COMP 3</u>	
Radiation and heating functions	7150
Surface wind magnitude	7490
Radiation constants	7590
Solar declination	7740
Surface topography (ocean, ice, bare land, snow- covered land)	7820
Pressure variables	8030
Temperature and moisture variables, and test for dry-adiabatic instability	8180
Ground temperature and wetness	8540
Large-scale precipitation	8610
Middle-level convection	8700
Preparation for air/earth interaction	8900
Surface temperature	8970
Penetrating and low-level convection	9140
Cloudiness	9400
Long-wave radiation	9750
Surface albedo	10240

Calculation	Initial Instruction
<u>COMP 3</u>	
Solar (short-wave) radiation	10430
Ground temperature	11020
Sensible heat flux and evaporation	11220
Moisture budget	11300
Total heating	11410
Surface friction	11500
Areal smoothing of heating	11850
<u>COMP 4</u>	
Horizontal momentum diffusion (inoperative in present version)	12270
Areal smoothing of lapse rate	12700

### 3. Common and Equivalence Statements

Most of the variables and constants of the program are communicated between the subprograms via a common block, stored in the single array BCØMN. The following equivalents should be noted:

BCØMN(1)--BCØMN(800) equivalent to C(1)--C(800)

where C(K) is defined to be equivalent to all the constants and one-dimensional arrays [and MAPLST(3, 40)],

BCØMN(801)--BCØMN(67040) equivalent to QTØT(1,1,1)--QTØT(46,72,20)

where QTØT is equivalent to all the two- and three-dimensional arrays,

QTØT(1,1,1)--QTØT(46,72,9) equivalent to Q(1,1,1)--Q(46,72,9)

QTØT(1,1,10)--QTØT(46,72,20) equivalent to QT(1,1,1)--QT(46,72,11)

and

Q(J,I,1) equivalent to P(J,I)	surface pressure ( $\pi$ )
Q(J,I,2) equivalent to U(J,I,1)	level 1 zonal wind ( $u_1$ )
Q(J,I,3) equivalent to U(J,I,2)	level 3 zonal wind ( $u_3$ )
Q(J,I,4) equivalent to V(J,I,1)	level 1 meridional wind ( $v_1$ )
Q(J,I,5) equivalent to V(J,I,2)	level 3 meridional wind ( $v_3$ )
Q(J,I,6) equivalent to T(J,I,1)	level 1 temperature ( $T_1$ )
Q(J,I,7) equivalent to T(J,I,2)	level 3 temperature ( $T_3$ )
Q(J,I,8) equivalent to Q3(J,I)	moisture ( $q_3$ )
Q(J,I,9) equivalent to TØPØG(J,I)	surface elevation and ocean temperature

The array QT(J,I,K) for K = 1 to 8 is similarly equivalent to all the temporary and intermediate values of the above quantities, i.e., PT(J,I), UT(J,I,K), etc. Occasionally Q and QT are used in the program rather than the original variables, especially in the time steps where all Q quantities are treated at once (see, for example, instructions 1960 to 2220). The array QT is also equivalent to all other two- and three-dimensional arrays in the program not requiring permanent storage. The common, dimension, and equivalence statements are given on the immediately following pages.

CODE LISTING

```

C*****00000010
C*****00000020
C*00000030
C*00000040
C* COMMON BLOCK FOR MINTZ-ARAKAWA TWO-LEVEL GENERAL CIRCULATION MODEL 00000050
C*00000060
C*00000070
C*****00000080
C*****00000090
COMMON GW,GT
      C D M M O N
      * BCDMN
      * D I M E N S I O N
      * BCDMN(67040), C(800), QTOT(46,72,20), Q(46,72,9), QT(46,72,11) 00000140
      *, P(46,72), U(46,72,2), V(46,72,2), T(46,72,2), Q3(46,72) 00000150
      *, PT(46,72), UT(46,72,2), VT(46,72,2), TT(46,72,2), Q3T(46,72) 00000160
      *, FD(46,72), H(46,72,2), PU(46,72), TD(46,72) 00000170
      *, PHI(46,72), W(46,72), TOPDG(46,72) 00000180
      *, CONV(46,72), PV(46,72), SD(46,72) 00000190
      *, GW(46,72), GT(46,72), QD(46,72,9) 00000200
      *, WORK1(46,72), WORK2(46,72) 00000210
      *, TS(46,72), SN(46,72) 00000220
      * D I M E N S I O N
      * LAT(46), DXU(46), DXP(46), DYU(46), DYP(46) 00000230
      *, SINL(46), COSL(46), AXU(46), AXV(46), AYU(46), AYV(46) 00000240
      *, DXYP(46), F(46), SIG(2), AMONTH(3), XLABL(9), MAPLST(3,40) 00000250
C      DXV AND DYV ARE INTERM VARIABLES ONLY 00000260
      *, DXV(46), DYV(46) 00000270
      * E Q U I V A L E N C E
      * (QTOT(1),Q(1)), (QTOT(29809),QT(1)), (BCDMN(1),C(1)) 00000280
      *, (BCDMN(801),QTOT(1)), (Q(1),P(1)), (Q(1,1,2),U(1)) 00000290
      *, (Q(1,1,4),V(1)), (Q(1,1,6),T(1)), (Q(1,1,8),Q3(1)) 00000300
      *, (Q(1,1,9),TOPDG(1)), (QT(1),QD(1),PT(1)) 00000310
      *, (QT(1,1,2),UT(1),WORK1(1)) 00000320
      *, (QT(1,1,3),TS(1)) 00000330
      *, (QT(1,1,4),VT(1),WORK2(1)) 00000340
      *, (QT(1,1,5),SN(1)) 00000350
      *, (QT(1,1,6),TT(1)), (QT(1,1,8),Q3T(1)) 00000360
      *, (QT(1,1,9),CONV(1),SO(1)) 00000370
      *, (QT(1,1,10),H(1),PV(1),PHI(1),W(1)) 00000380
      *, (QT(1,1,11),PU(1),FD(1),TD(1)) 00000390
      * E Q U I V A L E N C E
      * (C(1),JM), (C(2),IM), (C(3),JTP), (C(4),KTP), (C(5),LTP) 00000400
      *, (C(6),MTP), (C(7),NOOUT), (C(8),RESTR), (C(9),TAU) 00000410
      *, (C(10),TAUI), (C(11),TAUD), (C(12),TAUD), (C(13),TAUE) 00000420
      *, (C(14),TAUH), (C(15),TAUC), (C(16),ID), (C(17),DT) 00000430
      *, (C(18),DLAT), (C(19),DLON), (C(20),RAD), (C(21),RSOIST) 00000440
      *, (C(22),DCLK), (C(23),SINO), (C(24),COSD), (C(25),TOFDAY) 00000450
      *, (C(26),MNTHDY), (C(27),DAYPYR), (C(28),ROTPER), (C(29),SOEDY) 00000460
      *, (C(30),SDEYR), (C(31),EQNX), (C(32),APHEL), (C(33),DECMAX) 00000470
      *, (C(34),ECCN), (C(35),DAY), (C(36),GRAV), (C(37),RGAS) 00000480
      *, (C(38),KAPA), (C(39),PSF), (C(40),PTRDP), (C(41),PSL) 00000490
      *, (C(42),TCNV), (C(44),A), (C(45),NCYCLE) 00000500
      *, (C(46),NC3), (C(47),FM), (C(48),ED) 00000510
      *, (C(57),PI), (C(58),ZMM) 00000520
      *, (C(59),NPOL), (C(60),SPOL), (C(61),MRCH), (C(62),STAGJ) 00000530
      * 00000540
      * 00000550
      * 00000560

```

* , (C(63),STAGI), (C(64),SIG(1)), (C(66),AMONTH(1))	00000570
F Q U I V A L E N C E	00000580
* (C(69),XLABL(1)), (C(78),LAT(1)), (C(124),OXU(1))	00000590
* , (C(170),OXP(1)), (C(216),OYU(1)), (C(262),OYP(1))	00000600
* , (C(308),OXYP(1)), (C(354),F(1)), (C(400),SINL(1))	00000610
* , (C(446),COSL(1)), (C(492),AXU(1)), (C(538),AXV(1))	00000620
* , (C(584),AYU(1)), (C(630),AYV(1)), (C(676),MAPLST(1))	00000630
* , (C(797),NSTEP), (C(798),DLIC)	00000640
* , (C(799),TREADY), (SINT,ISINT)	00000650
* , (DXV(1),DXP(1)), (DYV(1),OYP(1))	00000660
C	00000670
REAL LAT, KAPA, NPOL	00000680
LOGICAL KEYS*1,BIT,MAPGEN,RESTR,KEY,TREADY	00000690
COMMON /VKEYV/ KEYS(32)	00000700
INTEGER SOEDY,SDEYR	00000710

```

C*****00000010
C*****00000020
C*00000030
C*00000040
C* MINTZ-ARAKAWA TWO-LEVEL ATMOSPHERIC GENERAL CIRCULATION MODEL 00000050
C*00000060
C*00000070
C*****00000080
C*****00000090
C00000100
C00000110
C C O N T R O L 00000120
/*00000130
// DD DISP=OLD,DSN=MES727.ABN.COMMON 00000140
// DD *00000150
LOGICAL EVENT,CHECK,PASS2,EVNTH,NOOUT,VIVA 00000160
DIMENSION CXXX(800) 00000170
EVENT(XTAU)=MOD(NSTEP,IFIX(XTAU*3600./DT+0.1)) .EQ. 0 00000180
PASS2=.FALSE. 00000190
DO 100 J=1,32 00000200
100 KEYS(J)=.FALSE. 00000210
200 KNT=0 00000220
RESTRT=.TRUE. 00000230
VIVA=.TRUE. 00000240
CALL INPUT 00000250
C00000260
C00000270
NSTEP=TAU*3600./DT+0.1 00000280
RESTRT=.FALSE. 00000290
C00000300
C00000310
C00000320
C00000330
310 NSTEP=NSTEP+1 00000340
TAU=FLOAT(NSTEP)*ABS(DT)/3600.+1.E-3 00000350
IF (TAU.GT.TAUE) GO TO 1200 00000360
TOFDAY=LMOD(TAU,ROTPER) 00000370
NOOUT=.NOT.(EVNT(TAU)) .OR. KEY(-8)) 00000380
IF (NOOUT .OR. MOD(NSTEP,NC3) .EQ. 0) GO TO 320 00000390
NOOUT=.TRUE. 00000400
KEYS(8)=.TRUE. 00000410
320 CONTINUE 00000420
C00000430
CALL STEP 00000440
IF (EVENT (24.)) CALL GMP 00000450

```



C		
C	VARIOUS CHECKING AND HISTORY OPTIONS	00000460
C		00000470
	630 IF (EVENT(TAUD)) CALL SNET	00000480
	IDAY=TAU/ROTPER	00000490
	IF (EVENT(TAUH)) GO TO 1000	00000500
	GO TO 310	00000510
	1000 CONTINUE	00000520
	READ (KTP) TAUX	00000530
	IF (TAUX.GT.0.0) GO TO 1100	00000540
	IF (ABS(TAU-TAUH+TAUX).GT..01) GO TO 1100	00000550
	1001 CONTINUE	00000560
	BACKSPACE KTP	00000570
	WRITE (KTP) TAU, C	00000580
	CALL OUTAPE(KTP,2)	00000590
	PRINT 1005,TAU	00000600
	1005 FORMAT (1X,'WRITE TAPE ',F8.2)	00000610
	GO TO 310	00000620
	1100 WRITE (MTP,1110) TAUX,TAUX	00000630
	1110 FORMAT (1X,'SOME MESS ON TAPE ',1X,E12.5,1X,IR)	00000640
	CALL EXIT	00000650
	1200 WRITE (MTP,1210) TAU	00000660
	1210 FORMAT (1X,'TERMINATING AS REQUIRED AT TAU=',F8.2)	00000670
	STOP	00000680
C		00000690
	9200 FORMAT(' WMSG020 MINTZ-ARAKAWA GLOBAL WEATHER MODEL NOW RUNNING')	00000700
	9670 FORMAT(' WMSG040 (' ,A4,') SWITCHING FROM TAPE ',I2,' TO TAPE ',I2,	00000710
	2' ON DAY ',I4,' / HOUR ',F6.3)	00000720
	9680 FORMAT(' WMSG035 SIM TIME IS DAY ',I4,' HOUR ',F7.3)	00000730
	9715 FORMAT(' WMSG036 (' ,A4,') HAS STOPPED AT DAY ', I4,' / HOUR ',	00000740
	2 F7.3)	00000750
C		00000760
C		00000770
	END	00000780
		00000790

```

SUBROUTINE OUTAPE(K,I)
// DD DISP=OLD,DSN=MES727.ABN.COMMON
// DD *
IF(I.EQ.2) GO TO 20
READ (K) P
READ (K) U
READ (K) V
READ (K) T
READ (K) Q3
READ (K) TOPOG
READ (K) PT
READ (K) GW
READ (K) TS
READ (K) GT
READ (K) SN
READ (K) TT
READ (K) Q3T
READ (K) SD
READ (K) H
READ (K) TD
RETURN
20 CONTINUE
WRITE (K) P
WRITE (K) U
WRITE (K) V
WRITE (K) T
WRITE (K) Q3
WRITE (K) TOPOG
WRITE (K) PT
WRITE (K) GW
WRITE (K) TS
WRITE (K) GT
WRITE (K) SN
WRITE (K) TT
WRITE (K) Q3T
WRITE (K) SD
WRITE (K) H
WRITE (K) TD
TAUX=-ABS(TAU)
WRITE (K) TAUX, C
BACKSPACE K
C THE NEGATIVE RECORD PREVENTS NOISE, MISSING RECORDS,
C AND MISSING TRAILER LABELS.
RETURN
END
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00000800  
00000810  
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00001000  
00001010  
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00001080  
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00001100  
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00001120  
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00001180  
00001190  
00001200  
00001210  
00001220  
00001230  
00001240

```

      * S U B R O U T I N E
      * GMP
/*
// DD DISP=OLD,DSN=MES727.AHN.COMMON
// DD *
      DIMENSION ZM(46)
      FIM=1M
      DO 135 J=1,JM
      ZM(J)=0.0
      DO 136 I=1,IM
136 ZM(J)=ZM(J) + P(J,I)
135 ZM(J)=ZM(J)/FIM
      WTM=0.
      ZMM=0.
      DO 137 J=1,JM
      WTM = WTM + ABS(DXYP(J))
137 ZMM = ZMM + ZM(J)*ABS(DXYP(J))
      ZMM=ZMM/WTM + PTRDP
      DELTAP = PSF - ZMM
      DO 301 I=1,IM
      DO 301 J=1,JM
301 P(J,I) = P(J,I) + DELTAP
      WRITE(6,138) DELTAP
138 FORMAT(' PRESSURE ADDED = ',F16.8)
      RETURN
      END

```

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```

<u>FUNCTION VPHI4 (J,I)</u>	00001510
C	00001520
/*	00001530
// DD DISP=OLD,DSN=MES727.ARN.COMMON	00001540
// DD *	00001550
VPHI4=0.	00001560
IF (TOPNG(J,I).LT. 1.0) VPHI4=AMOD(-TOPNG(J,I),10.E5)	00001570
C	00001580
RETURN	00001590
END	00001600

<u>FUNCTION IPK(IL,IR)</u>	00001610
INTEGER IHALF*2(2)	00001620
EQUIVALENCE (IHALF(1),IWD)	00001630
IHALF(1)=IL	00001640
IHALF(2)=IR	00001650
IPK=IWD	00001660
RETURN	00001670
ENTRY IRH(IPKWD)	00001680
IWD=IPKWD	00001690
IRH=IHALF(2)	00001700
RETURN	00001710
ENTRY ILH(IPKWD)	00001720
IWD=IPKWD	00001730
ILH=IHALF(1)	00001740
RETURN	00001750
END	00001760

<u>LOGICAL FUNCTION KEY(M)</u>	00001770
LOGICAL KEYS*1(32)	00001780
COMMON /VKEYV/ KEYS	00001790
N=IABS(M)	00001800
KEY=KEYS(N)	00001810
IF (M.LT. 0) KEYS(N)=.FALSE.	00001820
RETURN	00001830
END	00001840

<u>SUBROUTINE STEP</u>		00001850
// DD	DISP=OLD,DSN=MES727.ABN.COMMON	00001860
// DD	*	00001870
C		00001880
C	MAIN LOOP OF INTEGRATION	00001890
C	FORWARD STEP (CENTERED IN SPACE)	00001900
C		00001910
	MRCH=1	00001920
	DO 310 K=1,R	00001930
	DO 310 J=1,IM	00001940
	DO 310 J=1,JM	00001950
310	QT(J,I,K)=Q(J,I,K)	00001960
	THRP=TAU/24.	00001970
	PRINT 9999,TAU,THRP	00001980
9999	FORMAT (IX,'TIME=',2X,F8.2,2X,F9.4)	00001990
	CALL COMP1	00002000
	CALL COMP2	00002010
	DO 360 K=1,R	00002020
	DO 360 J=1,IM	00002030
	DO 360 J=1,JM	00002040
	TEMP=Q(J,I,K)	00002050
	Q(J,I,K)=QT(J,I,K)	00002060
360	QT(J,I,K)=TEMP	00002070
C		00002080
C	BACKWARD STEP	00002090
C		00002100
	NS=MOD(NSTEP,NCYCLE)	00002110
	MRCH=2	00002120
	IF(NS.EQ.1) MRCH=3	00002130
	IF(NS.EQ.2) MRCH=4	00002140
	CALL COMP1	00002150
	CALL COMP2	00002160
	DO 380 K=1,R	00002170
	DO 380 J=1,IM	00002180
	DO 380 J=1,JM	00002190
	TEMP=Q(J,I,K)	00002200
	Q(J,I,K)=QT(J,I,K)	00002210
380	QT(J,I,K)=TEMP	00002220
C		00002230
	IF (MOD(NSTEP,NC3).NE.0) GO TO 400	00002240
	CALL COMP4	00002250
	CALL COMP3	00002260
400	RETURN	00002270
	END	00002280

```

SUBROUTINE COMP1
/*
// DD DISP=OLD,DSN=MES727.ARN.COMMON
// DD *
JMM1=JM-1
IMM2=IM-2
FIM=IM
SIG1=SIG(1)
SIG3=SIG(2)
C
C
C MRCH=1      CENTERED IN SPACE AND FORWARD IN TIME
C MRCH=2      CENTERED IN SPACE AND BACKWARD IN TIME
C MRCH=3      UP-RIGHT  UNCENTERED IN SPACE AND BACKWARD IN TIME
C MRCH=4      DOWN-LEFT UNCENTERED IN SPACE AND BACKWARD IN TIME
C
C TIME EXTRAPOLATION INTERVAL FOR ADVECTION TERMS
C
C TEXCO=DT
C IF(MRCH.EQ.1) TEXCO=0.5*DT
C
C PREPARATION FOR TIME EXTRAPOLATION
C TRANSFORMATION TO AREA-PRESSURE WEIGHTED VARIABLES
C QT CONTAINS VARIABLES TO WHICH TENDENCIES ARE TO BE ADDED
C
DO 2100 I=1,IM
DO 2100 J=1,JM
FD(J,I)=PT(J,I)*DXYP(J)
2100 Q3T(J,I)=Q3T(J,I)*FD(J,I)
DO 2120 L=1,2
DO 2120 I=1,IM
IP1=MOD(I,IM)+1
DO 2110 J=1,JM
2110 TT(J,I,L)=TT(J,I,L)*FD(J,I)
DO 2120 J=2,JM
FDU=0.25*(FD(J,I)+FD(J,IP1)+FD(J-1,I)+FD(J-1,IP1))
IF (J .EQ. 2) FDU=0.25*(FD(2,I)+FD(2,IP1))+FD(1,I)
IF (J .EQ. JM) FDU=0.25*(FD(JM-1,I)+FD(JM-1,IP1))+FD(JM,I)
UT(J,I,L)=UT(J,I,L)*FDU
2120 VT(J,I,L)=VT(J,I,L)*FDU
C

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```

```

C
C      COMPUTING MASS FLUX * P      PU *
C      * PV      UV *
C
2149 L=1
2150 DO 2160 I=1,IM
      IP1=MOD(I,IM)+1
      DO 2160 J=2,JMM1
        IF(MRCH .LE. 2) PU(J,I)=0.25*(DYU(J)*U(J,I,L)+DYU(J+1)*U(J+1,I,L))
        IF(MRCH .EQ. 3) PU(J,I)=0.5*DYU(J+1)*U(J+1,I,L)
        IF(MRCH .EQ. 4) PU(J,I)=0.5*DYU(J)*U(J,I,L)
2160 CONTINUE
C
      CALL AVRX(11)
C
      DO 2180 I=1,IM
        IP1=MOD(I,IM)+1
        IM1=MOD(I+IMM2,IM)+1
        DO 2170 J=2,JMM1
          2170 PU(J,I)=PU(J,I)*(P(J,I)+P(J,IP1))
          DO 2180 J=2,JM
            IF(MRCH .LE. 2) PV(J,I)=0.25*DXU(J)*(V(J,I,L)+V(J,IM1,L))
            *
            *(P(J,I)+P(J-1,I))
            IF(MRCH .EQ. 3) PV(J,I)=0.5*DXU(J)*V(J,I,L)*(P(J,I)+P(J-1,I))
            IF(MRCH .EQ. 4) PV(J,I)=0.5*DXU(J)*V(J,IM1,L)*(P(J,I)+P(J-1,I))
2180 CONTINUE
C
      EQUIVALENT PU AT POLES.  PV(1,I) IS USED AS A WORKING SPACE.
C
      VM1=0.0
      VM2=0.0
      DO 2185 I=1,IM
        VM1=VM1+PV(2,I)
2185 VM2=VM2+PV(JM,I)
      VM1=VM1/FIM
      VM2=VM2/FIM
      PV(1,1)=0.0
      DO 2190 I=2,IM
        2190 PV(1,I)=PV(1,I-1)+(PV(2,I)-VM1)
        VM1=0.0
        DO 2192 I=1,IM
          2192 VM1=VM1+PV(1,I)
          VM1=VM1/FIM
          DO 2195 I=1,IM
            2195 PU(1,I)=-(PV(1,I)-VM1)*3.0
            PV(1,I)=0.0
            DO 2200 I=2,IM
              2200 PV(1,I)=PV(1,I-1)+(PV(JM,I)-VM2)
              VM2=0.0
              DO 2202 I=1,IM
                2202 VM2=VM2+PV(1,I)
                VM2=VM2/FIM
                DO 2205 I=1,IM
                  2205 PU(JM,I)=(PV(1,I)-VM2)*3.0
C

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00002800
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00002990
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00003010
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C	HORIZONTAL ADVECTION OF THERMODYNAMIC ENERGY AND MOISTURE EQUATIONS	00003250
	FXC0=0.5*TEXC0	00003260
	DN 2220 I=1,IM	00003270
	IP1=MOD(I,IM)+1	00003280
	DN 2210 J=2,JMM1	00003290
	FLUX=FXC0*PU(J,I)	00003300
	FLUXT=FLUX*(T(J,I,L)+T(J,IP1,L))	00003310
	IF ((J.EQ. 2 .OR. J.EQ. JMM1) .AND. FLUX .LT. 0.)	00003320
	* FLUXT=FLUX*2.*T(J,IP1,L)	00003330
	IF ((J.EQ. 2 .OR. J.EQ. JMM1) .AND. FLUX .GE. 0.0)	00003340
	* FLUXT=FLUX*2.*T(J,I,L)	00003350
	TT(J,I,L)=TT(J,I,L)-FLUXT	00003360
	TT(J,IP1,L)=TT(J,IP1,L)+FLUXT	00003370
	IF (L.EQ.1) FLUX=-0.25*FLUX	00003380
	IF (L.EQ.2) FLUX=1.25*FLUX	00003390
	Q3M=Q3(J,I)+Q3(J,IP1)	00003400
	IF(Q3M.LT.10.E-10) GO TO 2210	00003410
C 10.	E-10 IS A RELATIVELY SMALL NUMBER	00003420
	FLUXQ=FLUX*Q3M	00003430
	IF(Q3(J,I).LT.Q3(J,IP1) .AND. FLUX.GT.0.)	00003440
	* FLUXQ=FLUX*4.*Q3(J,I)*Q3(J,IP1)/Q3M	00003450
	IF(Q3(J,I).GT.Q3(J,IP1) .AND. FLUX.LT.0.)	00003460
	* FLUXQ=FLUX*4.*Q3(J,I)*Q3(J,IP1)/Q3M	00003470
	Q3T(J,I)=Q3T(J,I)-FLUXQ	00003480
	Q3T(J,IP1)=Q3T(J,IP1)+FLUXQ	00003490
2210	CONTINUE	00003500
	DN 2220 J=2,JM	00003510
	FLUX=FXC0*PV(J,I)	00003520
	FLUXT=FLUX*(T(J,I,L)+T(J-1,I,L))	00003530
	IF (J.FQ. 2 .AND. FLUX .LT. 0.) FLUXT=FLUX*2.*T(2,I,L)	00003540
	IF (J.FQ. 2 .AND. FLUX .GT. 0.) FLUXT=FLUX*2.*T(JM-1,I,L)	00003550
	IF (J.FQ. 2 .AND. FLUX .GE. 0.) FLUXT=FLUX*2.*T(1,I,L)	00003560
	IF (J.EQ. JM .AND. FLUX .LF. 0.) FLUXT=FLUX*2.*T(JM,I,L)	00003570
	TT(J,I,L)=TT(J,I,L)+FLUXT	00003580
	TT(J-1,I,L)=TT(J-1,I,L)-FLUXT	00003590
	IF (L.FQ.1) FLUX=-0.25*FLUX	00003600
	IF (L.FQ.2) FLUX=1.25*FLUX	00003610
	Q3M=Q3(J,I)+Q3(J-1,I)	00003620
	IF(Q3M.LT.10.E-10) GOTO 2220	00003630
	10.E-10 IS AN ARBITRARY LOWER LIMIT	00003640
	FLUXQ=FLUX*Q3M	00003650
	IF(Q3(J,I).LT.Q3(J-1,I) .AND. FLUX.LT.0.)	00003660
	* FLUXQ=FLUX*4.*Q3(J,I)*Q3(J-1,I)/Q3M	00003670
	IF(Q3(J,I).GT.Q3(J-1,I) .AND. FLUX.GT.0.)	00003680
	* FLUXQ=FLUX*4.*Q3(J,I)*Q3(J-1,I)/Q3M	00003690
	Q3T(J,I)=Q3T(J,I)-FLUXQ	00003700
	Q3T(J-1,I)=Q3T(J-1,I)+FLUXQ	00003710
2220	CONTINUE	00003720
		00003730
C		00003740



C	HORIZONTAL ADVECTION OF EQUATION OF MOTION	00003750
C		
	FXCO=TEXCO/12.	00003760
	FXCO1=TEXCO/24.	00003770
	DO 2320 I=1,IM	00003780
	IP1=MOD(I,IM)+1	00003790
	IM1=MOD(I+IMM2,IM)+1	00003800
	DO 2310 J=2,JM	00003810
	FLUX=FXCO*(PU(J,I)+PU(J-1,I)+PU(J,IM1)+PU(J-1,IM1))	00003820
	FLUXU=FLUX*(U(J,I,L)+U(J,IM1,L))	00003830
	UT(J,I,L)=UT(J,I,L)+FLUXU	00003840
	UT(J,IM1,L)=UT(J,IM1,L)-FLUXU	00003850
	FLUXV=FLUX*(V(J,I,L)+V(J,IM1,L))	00003860
	VT(J,I,L)=VT(J,I,L)+FLUXV	00003870
2310	VT(J,IM1,L)=VT(J,IM1,L)-FLUXV	00003880
	DO 2320 J=2,JMM1	00003890
	FLUX=FXCO*(PV(J,I)+PV(J,IP1)+PV(J+1,I)+PV(J+1,IP1))	00003900
	FLUXU=FLUX*(U(J,I,L)+U(J+1,I,L))	00003910
	UT(J+1,I,L)=UT(J+1,I,L)+FLUXU	00003920
	UT(J,I,L)=UT(J,I,L)-FLUXU	00003930
	FLUXV=FLUX*(V(J,I,L)+V(J+1,I,L))	00003940
	VT(J+1,I,L)=VT(J+1,I,L)+FLUXV	00003950
	VT(J,I,L)=VT(J,I,L)-FLUXV	00003960
	FLUX=FXCO1*(PU(J,I)+PU(J,IM1)+PV(J,I)+PV(J+1,I))	00003970
	FLUXU=FLUX*(U(J+1,I,L)+U(J,IM1,L))	00003980
	UT(J+1,I,L)=UT(J+1,I,L)+FLUXU	00003990
	UT(J,IM1,L)=UT(J,IM1,L)-FLUXU	00004000
	FLUXV=FLUX*(V(J+1,I,L)+V(J,IM1,L))	00004010
	VT(J+1,I,L)=VT(J+1,I,L)+FLUXV	00004020
	VT(J,IM1,L)=VT(J,IM1,L)-FLUXV	00004030
	FLUX=FXCO1*(-PU(J,I)-PU(J,IM1)+PV(J,I)+PV(J+1,I))	00004040
	FLUXU=FLUX*(U(J+1,IM1,L)+U(J,I,L))	00004050
	UT(J+1,IM1,L)=UT(J+1,IM1,L)+FLUXU	00004060
	UT(J,I,L)=UT(J,I,L)-FLUXU	00004070
	FLUXV=FLUX*(V(J+1,IM1,L)+V(J,I,L))	00004080
	VT(J+1,IM1,L)=VT(J+1,IM1,L)+FLUXV	00004090
2320	VT(J,I,L)=VT(J,I,L)-FLUXV	00004100
C		00004110
		00004120

C	CONTINUITY EQUATION	00004130
C		00004140
	DO 2400 I=1,IM	00004150
	IM1=MOD(I+IMM2,IM)+1	00004160
	DO 2400 J=1,JM	00004170
	IF (J.EQ.1) CONVM=-PV(2,I)*0.5	00004180
	IF (J.EQ.JM) CONVM=PV(JM,I)*0.5	00004190
	IF (J.GT.1 .AND. J.LT.JM) CONVM=-(PU(J,I) -PU(J,IM1)	00004200
	* +PV(J+1,I)-PV(J,I) )*0.5	00004210
	IF (L.EQ.1) CONV(J,I)=CONVM	00004220
	IF (L.EQ.2) PV(J,I)=CONVM	00004230
2400	CONTINUE	00004240
	IF(L.EQ.2) GO TO 2410	00004250
	L=2	00004260
	GO TO 2150	00004270
2410	CONTINUE	00004280
C		00004290
C	CONV IS MASS CONVERGENCE AT L=1 AND PV IS THAT AT L=2.	00004300
C		00004310
2411	PB1=0.0	00004320
	PB2=0.0	00004330
	PB3=0.0	00004340
	PB4=0.0	00004350
	DO 2402 I=1,IM	00004360
	PR1=PB1+CONV(1,I)	00004370
	PR2=PB2+CONV(JM,I)	00004380
	PB3=PB3+PV(1,I)	00004390
2402	PB4=PB4+PV(JM,I)	00004400
	PR1=PR1/FIM	00004410
	PR2=PR2/FIM	00004420
	PB3=PB3/FIM	00004430
	PB4=PB4/FIM	00004440
	DO 2405 I=1,IM	00004450
	CONV(1,I)=PR1	00004460
	CONV(JM,I)=PR2	00004470
	PV(1,I)=PB3	00004480
2405	PV(JM,I)=PB4	00004490
	DO 2420 I=1,IM	00004500
	DO 2420 J=1,JM	00004510
	PIT=CONV(J,I)+PV(J,I)	00004520
	SD(J,I)=CONV(J,I)-PV(J,I)	00004530
	PT(J,I)=PT(J,I)+DT*PIT/DXYP(J)	00004540

C		00004550
C	ENERGY CONVERSION TERM IN THERMODYNAMIC ENERGY EQUATION	00004560
C		00004570
	PL1=PTROP+SIG1*P(J,I)	00004580
	PL3=PTROP+SIG3*P(J,I)	00004590
	PK1=PL1**KAPA	00004600
	PK3=PL3**KAPA	00004610
	TETAM=0.5*(T(J,I,1)/PK1+T(J,I,2)/PK3)	00004620
	TT(J,I,1)=TT(J,I,1)+DT*(SIG1*KAPA*P(J,I)*T(J,I,1)*PIT/PL1	00004630
	* -SD(J,I)*TETAM*PK1)	00004640
	TT(J,I,2)=TT(J,I,2)+DT*(SIG3*KAPA*P(J,I)*T(J,I,2)*PIT/PL3	00004650
	* +SD(J,I)*TETAM*PK3)	00004660
	2420 CONTINUE	00004670
C		00004680
C	VERTICAL ADVECTION OF MOMENTUM	00004690
C		00004700
	2500 FXCD=0.5*TEXCD	00004710
	DO 2510 I=1,IM	00004720
	IP1=MOD(I,IM)+1	00004730
	DO 2510 J=2,JM	00004740
	SOU=0.25*(SD(J,I)+SD(J,IP1)+SD(J-1,I)+SD(J-1,IP1))	00004750
	IF (J .EQ. 2) SOU=0.25*(SD(2,I)+SD(2,IP1))+SD(1,I)	00004760
	IF (J .EQ. JM) SOU=0.25*(SD(JM-1,I)+SD(JM-1,IP1))+SD(JM,I)	00004770
	VAD=FXCD*SOU*(U (J,I,1)+U (J,I,2))	00004780
	UT(J,I,2)=UT(J,I,2)+VAD	00004790
	UT(J,I,1)=UT(J,I,1)-VAD	00004800
	VAD=FXCD*SOU*(V (J,I,1)+V (J,I,2))	00004810
	VT(J,I,2)=VT(J,I,2)+VAD	00004820
	2510 VT(J,I,1)=VT(J,I,1)-VAD	00004830
C		00004840
C		00004850
	RETURN	00004860
	END	00004870

<u>SUBROUTINE COMP2</u>		00004880
/*		00004890
// DD	DISP=OLD,DSN=MES727.ABN.COMMON	00004900
//	DD *	00004910
C		00004920
	JMM1=JM-1	00004930
	IMM2=IM-2	00004940
	FIM=IM	00004950
	TEXCO=DT	00004960
	IF(MRCH.EQ.1) TEXCO=0.5*DT	00004970
C	IF (KEY(31)) TEXCO=DT	00004980
	HRGAS=RGAS/2.	00004990
C		00005000
C	CORIDOLIS FORCE	00005010
C		00005020
	FXCO=0.125*TEXCO	00005030
	DO 3140 L=1,2	00005040
	DO 3110 I=1,IM	00005050
	IM1=MOD(I+IMM2,IM)+1	00005060
	FD(1,I)=0.0	00005070
	FD(JM,I)=0.0	00005080
	DO 3110 J=2,JMM1	00005090
3110	FD(J,I)=F(J)*DXYP(J)	00005100
	* +.25*(U(J,I,L)+U(J,IM1,L)+U(J+1,I,L)+U(J+1,IM1,L))	00005110
	* *(DXU(J)-DXU(J+1))	00005120
	DO 3140 I=1,IM	00005130
	IM1=MOD(I+IMM2,IM)+1	00005140
	DO 3140 J=2,JM	00005150
	ALPHA=FXCO*(P(J,I)+P(J-1,I))*(FD(J,I)+FD(J-1,I))	00005160
	UT(J,I,L)=UT(J,I,L)+ALPHA*V(J,I,L)	00005170
	UT(J,IM1,L)=UT(J,IM1,L)+ALPHA*V(J,IM1,L)	00005180
	VT(J,I,L)=VT(J,I,L)-ALPHA*U(J,I,L)	00005190
3140	VT(J,IM1,L)=VT(J,IM1,L)-ALPHA*U(J,IM1,L)	00005200

C		00005210
C	PRESSURE GRADIENT	00005220
C		00005230
3200	DO 3340 L=1,2	00005240
C		00005250
C	COMPUTATION OF PHI	00005260
C		00005270
	DO 3210 I=1,IM	00005280
	DO 3210 J=1,JM	00005290
	PHI4=VPHI4(J,I)	00005300
	VPS1= P(J,I)*0.25/(P(J,I)*0.25 + PTROP)	00005310
	VPS3= P(J,I)*0.75/(P(J,I)*0.75 + PTROP)	00005320
	VPK1=((P(J,I)*.25+PTROP)/(P(J,I)*.75+PTROP))*KAPA	00005330
	VPK3=1./VPK1	00005340
	IF(L.FO.2) GO TO 3205	00005350
	COE1=(VPS1+0.5*(VPK3-1.)/KAPA)*HRGAS	00005360
	COE2=(VPS3+0.5*(1.-VPK1)/KAPA)*HRGAS	00005370
	PHI(J,I)=COE1*T(J,I,1)+COE2*T(J,I,2)+PHI4	00005380
	GO TO 3210	00005390
3205	COE3=(VPS1-0.5*(VPK3-1.)/KAPA)*HRGAS	00005400
	COE4=(VPS3-0.5*(1.-VPK1)/KAPA)*HRGAS	00005410
	PHI(J,I)=COE3*T(J,I,1)+COE4*T(J,I,2)+PHI4	00005420
3210	CONTINUE	00005430
C		00005440
C	GRADIENT OF PHI	00005450
C		00005460
	FXC0=0.25*DT	00005470
	FXC01=0.5*DT	00005480
	DO 3220 I=1,IM	00005490
3220	PHI(I,1)=0.	00005500
	DO 3250 J=1,JM	00005510
	IP1=MOD(I,IM)+1	00005520
	IM1=MOD(I+IMM2,IM)+1	00005530
	DO 3250 J=2,JM	00005540
	TEMP1=(P(J,IP1)+P(J,I)) * (PHI(J,IP1)-PHI(J,I))	00005550
	P(J,I)=TEMP1	00005560
	TEMP2=(P(J,I)+P(J-1,I))*(PHI(J,I)-PHI(J-1,I))*DX(J)	00005570
	IF(MRCH .FO. 3) GO TO 3230	00005580
	IF(MRCH .FO. 4) GO TO 3240	00005590
C	MRCH= 1 OR 2. CENTERED IN SPACE.	00005600
	VT(J,I,L)=VT(J,I,L)-FXC0*TEMP2	00005610
	VT(J,IM1,L)=VT(J,IM1,L)-FXC0*TEMP2	00005620
	GO TO 3250	00005630
C	MRCH=3. UP-RIGHT UNCENTERED.	00005640
3230	VT(J,IM1,L)=VT(J,IM1,L)-FXC01*TEMP2	00005650
	GO TO 3250	00005660
C	MRCH=4. DOWN-LEFT UNCENTERED.	00005670
3240	VT(J,I,L)=VT(J,I,L)-FXC01*TEMP2	00005680
3250	CONTINUE	00005690
C		00005700

C	GRADIENT OF P	00005710
C	SIGMA*P*ALPHA IS STORED AT PHI	00005720
C		00005730
	DO 3260 I=1,IM	00005740
	DO 3260 J=1,JM	00005750
3260	PHI(J,I)=SIG(L)*P(J,I)*RGAS*T(J,I,L)/(PTROP+SIG(L)*P(J,I))	00005760
	DO 3290 I=1,IM	00005770
	IP1=MOD(I,IM)+1	00005780
	IM1=MOD(I+IMM2,IM)+1	00005790
	DO 3290 J=2,JM	00005800
	TEMP1=(PHI(J,IP1)+PHI(J,I))*(P(J,IP1)-P(J,I))	00005810
	PU(J,I)=TEMP1+PU(J,I)	00005820
	TEMP2=(PHI(J,I)+PHI(J-1,I))*(P(J,I)-P(J-1,I))*OXU(J)	00005830
	IF(MRCH.EQ.3) GO TO 3270	00005840
	IF(MRCH.EQ.4) GO TO 3280	00005850
C	MRCH = 1 OR 2. CENTERED IN SPACE.	00005860
	VT(J,I,L)=VT(J,I,L)-FXC0*TEMP2	00005870
	VT(J,IM1,L)=VT(J,IM1,L)-FXC0*TEMP2	00005880
	GO TO 3290	00005890
C	MRCH=3. UP-RIGHT UNCENTERED.	00005900
3270	VT(J,IM1,L)=VT(J,IM1,L)-FXC01*TEMP2	00005910
	GO TO 3290	00005920
C	MRCH=4. DOWN-LEFT UNCENTERED	00005930
3280	VT(J,I,L)=VT(J,I,L)-FXC01*TEMP2	00005940
3290	CONTINUE	00005950
C		00005960
	CALL AVRX(11)	00005970
C		00005980
	DO 3300 I=1,IM	00005990
	DO 3300 J=2,JM	00006000
	IF (MRCH.LE.2) UT(J,I,L)=UT(J,I,L)-FXC0*OYU(J)	00006010
	* (PU(J,I)+PU(J-1,I))	00006020
	IF(MRCH.EQ.3) UT(J,I,L)=UT(J,I,L)-FXC01*DYU(J)*PU(J,I)	00006030
	IF(MRCH.EQ.4) UT(J,I,L)=UT(J,I,L)-FXC01*OYU(J)*PU(J-1,I)	00006040
3300	CONTINUE	00006050

C		00006060
C	ENERGY CONVERSION TERM IN THERMODYNAMIC EQUATION.	00006070
C	SIGMA*P*ALPHA IS NOW STORED AT PHI	00006080
C		00006090
3310	FXC0=0.125*DT*KAPA/RGAS	00006100
	FXC01=0.25*DT*KAPA/RGAS	00006110
C		00006120
	DO 3320 I=1,IM	00006130
	IP1=MOD(I,IM)+1	00006140
	DO 3320 J=2,JMM1	00006150
	IF(MRCH.LE.2) TEMP=FXC0*(U(J+1,1,L)*DYU(J+1)+U(J,1,L)*DYU(J))	00006160
	IF(MRCH.EQ.3) TEMP=FXC01*U(J+1,1,L)*DYU(J+1)	00006170
	IF(MRCH.EQ.4) TEMP=FXC01*U(J,1,L)*DYU(J)	00006180
3320	PU(J,1)=TEMP	00006190
C		00006200
	CALL AVRX(11)	00006210
C		00006220
	DO 3330 I=1,IM	00006230
	IP1=MOD(I,IM)+1	00006240
	IM1=MOD(I+1MM2,IM)+1	00006250
	DO 3325 J=2,JMM1	00006260
	PU(J,1)=PU(J,1)*(PHI(J,IP1)+PHI(J,1))*(P(J,IP1)-P(J,1))	00006270
3325	TT(J,IP1,L)=TT(J,IP1,L)+PU(J,1)	00006280
	TT(J,1,L)=TT(J,1,L)+PU(J,1)	00006290
	DO 3330 J=2,JM	00006300
	IF(MRCH.LE.2) TEMP=FXC0*DXU(J)*(V(J,1,L)+V(J,IM1,L))	00006310
	IF(MRCH.EQ.3) TEMP=FXC01*DXU(J)*V(J,1,L)	00006320
	IF(MRCH.EQ.4) TEMP=FXC01*DXU(J)*V(J,IM1,L)	00006330
	TEMP=TEMP*(PHI(J,1)+PHI(J-1,1))*(P(J,1)-P(J-1,1))	00006340
	TT(J,1,L)=TT(J,1,L)+TEMP	00006350
3330	TT(J-1,1,L)=TT(J-1,1,L)+TEMP	00006360
3340	C(NTIME)	00006370
C		00006380
C	THIS IS THE END OF FORWARD OR CENTERED TYPE OF TIME EXTRAPOLATION	00006390

C		00006400
C	ADJUSTMENT AT THE POLES	00006410
C		00006420
	DO 3415 L=1,8	00006430
	IF(L.GT.1.AND.L.LT.6) GO TO 3415	00006440
	PB1=0.	00006450
	PH2=0.	00006460
	DO 3405 I=1,IM	00006470
	PH1=PB1+QT(1,I,L)	00006480
3405	PH2=PB2+QT(JM,I,L)	00006490
	PH1=PB1/FIM	0006500
	PH2=PB2/FIM	00006510
	DO 3410 I=1,IM	00006520
	QT(1,I,L)=PB1	00006530
3410	QT(JM,I,L)=PB2	00006540
3415	CONTINUE	00006550
3430	Q3T(JM,I)=PB2	00006560
C		00006570
C	RETURN TO UNWEIGHTED VARIABLES	00006580
C		00006590
	DO 3460 I=1,IM	00006600
	DO 3460 J=1,JM	00006610
	FD(J,I)=PT(J,I)*DXYP(J)	00006620
3460	Q3T(J,I)=Q3T(J,I)/FD(J,I)	00006630
	DO 3470 L=1,2	00006640
	DO 3470 I=1,IM	00006650
	IP1=MOD(I,IM)+1	00006660
	DO 3465 J=1,JM	00006670
3465	TT(J,I,L)=TT(J,I,L)/FD(J,I)	00006680
	DO 3470 J=2,JM	00006690
	FDU=0.25*(FD(J,I)+FD(J,IP1)+FD(J-1,I)+FD(J-1,IP1))	00006700
	IF (J .EQ. 2) FDU=0.25*(FD(2,I)+FD(2,IP1))+FD(1,I)	00006710
	IF (J .EQ. JM) FDU=0.25*(FD(JM-1,I)+FD(JM-1,IP1))+FD(JM,I)	00006720
	UT(J,I,L)=UT(J,I,L)/FDU	00006730
3470	VT(J,I,L)=VT(J,I,L)/FDU	00006740
	RETURN	00006750
C		00006760
	END	00006770



<u>S U B R O U T I N E</u>		
	* <u>AVRX(K)</u>	
/*		000067A0
// DD	DISP=(OLD,DSN=MFS727,ASN,CIMMFIN	00006790
// DD	*	00006A00
C	THIS SUBROUTINE USES UT(1,1,1) AS A WORKING SPACE	00006A10
		00006A20
	JMM1=JM-1	00006A30
	JMM2=JM-2	00006A40
	JE=JM/2+1	00006A50
	DEFF=DYP(JE)	00006A60
	DN 150 J=2,JMM1	00006A70
	DRAT=DEFF/DXP(J)	00006A80
	IF (DRAT .LT. 1.) GO TO 150	00006A90
	ALP=0.125*(DRAT-1.)	00006900
	NM=DRAT	00006910
	FNM=NM	00006920
	ALPHA=ALP/FNM	00006930
	DN 150 N=1,NM	00006940
	DN 120 I=1,IM	00006950
	IP1=MOD(I,IM)+1	00006960
	IM1=MOD(I+JMM2,IM)+1	00006970
120	UT(1,1,1)=QT(J,I,K)+ALPHA*(QT(J,IP1,K)+QT(J,IM1,K)-2.*QT(J,I,K))	00006980
	DN 130 I=1,IM	00006990
130	QT(J,I,K)=UT(1,1,1)	00007000
150	CONTINUE	00007010
C		00007020
	RETURN	00007030
	END	00007040
		00007050
		00007060

<u>S U B R O U T I N E</u>		
<u>COMP3</u>		
/*		00007070
//	DD DISP=OLD,DSN=MES727.ABN.COMMON	00007080
//	DD *	00007090
	EQUIVALENCE (KKK,XXX)	00007100
	LOGICAL NOOUT, ICE, LAND, OCEAN, SNOW, KEY	00007110
C		00007120
	TRANS(X)=1./(1.+1.75*X**.416)	00007130
	TRSW(X)=1.-.271*X**.303	00007140
C		00007150
	JMM1=JM-1	00007160
	JMM2=JM-2	00007170
	JMM2=JM-2	00007180
	JH=JM/2+1	00007190
	FIM=JM	00007200
	SIG1=SIG(1)	00007210
	SIG3=SIG(2)	00007220
	DSIG=SIG3-SIG1	00007230
C		00007240
	GWM=30.	00007250
	DTC3=FLOAT(NC3)*DT	00007260
	RCNV=DTC3/TCNV	00007270
	CLH=580./ .24	00007280
	P1OK=1000.**KAPA	00007290
	CT1=.005	00007300
	CT1D=8.64E4*CT1	00007310
	HICE=300.	00007320
	TICE=273.1	00007330
C		00007340
	PM=PSL-PTRDP	00007350
	COE=GRAV*100./(10.5*PM*1000.*0.24)	00007360
	COE1=COE*DTC3/(24.*3600.)	00007370
	SCALEU=COE*100.	00007380
	TSPD=DAY/DTC3	00007390
	SCALEP=TSPD*.5*(10./GRAV)*100.	00007400
	CONRAD=180./PI	00007410
	CNRX=CONRAD*.01	00007420
	FSDEDY=SDEDY	00007430
	SNOWN=(60.-15.*COS(.9863*(FSDEDY-24.668)/CONRAD))/CONRAD	00007440
	SNOWS=-60./CONRAD	00007450
C		00007460
C	SURFACE WIND MAGNITUDE	00007470
C		00007480
	DD 10 I=1,IM	00007490
	DD 10 J=2,JM	00007500
	US=2.*(SIG3*U(J,I,2)-SIG1*U(J,I,1))*0.7	00007510
	VS=2.*(SIG3*V(J,I,2)-SIG1*V(J,I,1))*0.7	00007520
10	FD(J,I)=US*US + VS*VS	00007530
	WMAG1=SQRT(.5*(FD(2,1)+FD(2,IM)))	00007540
	WMAGJM=SQRT(.5*(FD(JM,1)+FD(JM,IM)))	00007550
		00007560
		00007570

C		00007580
C	RAOIIATION CONSTANTS	00007590
C		00007600
	SO=2880./RSOIST	00007610
	ALC1=.7	00007620
	ALC2=.6	00007630
	ALC3=.6	00007640
	STBO=1.171E-7	00007650
	EFVC1=65.3	00007660
	EFVC2=65.3	00007670
	EFVC3=7.6	00007680
	CPART=.5*1.3071E7	00007690
	ROT = TOFOAY/ROTPER*2.0*PI	00007700
C		00007710
C	HEATING LOOP	00007720
C		00007730
	ON 370 I=1,IM	00007740
	IM1=M00(I+IMM2,IM)+1	00007750
	IP1=M00(I,IM)+1	00007760
	FIM1=I-1	00007770
	HACOS=CDSO*COS(ROT+FIM1*OLON)	00007780
	ON 380 J=1,JM	00007790
	COSZ=SINL(J)*SINO+COSL(J)*HACOS	00007800
C		00007810
C	SURFACE CONOITION	00007820
C		00007830
	TG00=TOPOG(J,I)	00007840
	OCEAN=TG00.GT.1.	00007850
	ICE=TG00.LF.-9.9F5	00007860
	LAND=.NOT.(ICE.OR.OCEAN)	00007870
	SNOW=LAND.AND.(LAT(J).GE.SNOWN.OR.LAT(J).LE.SNOWS)	00007880
	LANO=LANO.ANO..NOT.SNOW	00007890
	IF (.NOT.OCEAN) ZZZ=VPHI4(J,I)/GRAV	00007900
C	ORAG COEFFICIENT	00007910
	IF (J.EQ. 1) WMAG=WMAG1	00007920
	IF (J.EQ. JM) WMAG=WMAGJM	00007930
	IF (J.NE.1.AND.J.NE.JM) WMAG=SQRT(.25*(FO(J,I)+FO(J+1,I)	00007940
	X +FD(J,IM1)+FO(J+1,IM1))	00007950
	CD = .002	00007960
	IF (.NOT.OCEAN) CO=CD+0.006*ZZZ/5000.	00007970
	IF (OCEAN) CD = AMIN1((1.0+.07*WMAG)*.001,.0025)	00007980
	CS = CO*100.	00007990
	CS4 = .24*CS*24.*3600.	00008000
	FK1 = CD*(10.*GRAV)/(DSIG*PM)	00008010

C		00008020
C	PRESSURES	00008030
C		00008040
	SP=P(J,I)	00008050
	COLMR=PM/SP	00008060
	P4=SP+PTROP	00008070
	P4K=P4**KAPA	00008080
	PL1=SIG1*SP+PTROP	00008090
	PL2=.5*SP+PTROP	00008100
	PL3=SIG3*SP+PTROP	00008110
	PL1K=PL1**KAPA	00008120
	PL3K=PL3**KAPA	00008130
	PL2K=PL2**KAPA	00008140
	PTRK=PTROP**KAPA	00008150
	DPLK=PL3K-PL1K	00008160
C		00008170
C	TEMPERATURES AND TEST FOR DRY-ADIABATIC INSTABILITY	00008180
C		00008190
	T1=T(J,I,1)	00008200
	T3=T(J,I,2)	00008210
	THL1=T1/PL1K	00008220
	THL3=T3/PL3K	00008230
	IF (THL1 .GT. THL3) GO TO 310	00008240
	XX1=(T1+T3)/(PL1K+PL3K)	00008250
	T1=XX1*PL1K	00008260
	T3=XX1*PL3K	00008270
	T(J,I,1)=T1	00008280
	T(J,I,2)=T3	00008290
	THL1=T1/PL1K	00008300
	THL3=T3/PL3K	00008310
C		00008320
C	MOISTURE VARIABLES	00008330
C		00008340
310	ES1=10.0** (8.4051-2353.0/T1)	00008350
	ES3=10.0** (8.4051-2353.0/T3)	00008360
	P1CB=.1*PL1	00008370
	P3CB=.1*PL3	00008380
	P4CB=.1*P4	00008390
	QS1=.622*ES1/(P1CB-ES1)	00008400
	QS3=.622*ES3/(P3CB-ES3)	00008410
	GAM1=CLH*QS1*5418./T1**2	00008420
	GAM3=CLH*QS3*5418./T3**2	00008430
	Q3R=Q3(J,I)	00008440
	RH3=Q3R/QS3	00008450
C		00008460
C	TEMPERATURE EXTRAPOLATION AND INTERPOLATION FOR RADIATION	00008470
C		00008480
	ATEM=(THL3-THL1)/DPLK	00008490
	BTEM=(THL1*PL3K-THL3*PL1K)/DPLK	00008500
	TTROP=(ATEM*PTRK+BTEM)*PTRK	00008510
	T2=(ATEM*PL2K+BTEM)*PL2K	00008520

C		00008530
C	GROUND TEMPERATURE AND WETNESS	00008540
C	TG=TG00	00008550
	WET=1.0	00008560
	IF (.NOT.OCEAN) TG=GT(J,I)	00008570
	IF (LAND) WET=GW(J,I)	00008580
C		00008590
C	LARGE SCALE PRECIPITATION	00008600
C	PREC=0.	00008610
	IF (Q3R.LE.QS3) GO TO 1060	00008620
	PREC=(Q3R-QS3)/(1.+GAM3)	00008630
	T3=T3+CLH*PREC	00008640
	THL3=THL3/PL3K	00008650
	Q3R=Q3R-PREC	00008660
		00008670
C		00008680
C	CONVECTION	00008690
C		00008700
	1060 TETA1=THL1*P10K	00008710
	TETA3=THL3*P10K	00008720
	SS3 = TETA3*P4K/P10K	00008730
	SS2 = SS3 + 0.5*(TETA1-TETA3)*PL2K/P10K	00008740
	SS1 = SS2 + 0.5*(TETA1-TETA3)*PL2K/P10K	00008750
	HH3 = SS3 + CLH*Q3R	00008760
	HH3S = SS3 + CLH*QS3	00008770
	HH1S = SS1 + CLH*QS1	00008780
		00008790
C		00008800
C	MIDDLE LEVEL CONVECTION	00008810
C		00008820
	C1 = 0.	00008830
	C3 = 0.	00008840
	EX = HH3 - HH1S	00008850
	IF (EX.LE.0.) GO TO 1065	00008860
	C1 = RCNV*EX/(2.+GAM1)	00008870
	C3 = C1*(1.+GAM1)*(SS2-SS3)/(EX+(1.+GAM1)*(SS1-SS2))	00008880
C		00008890
C	PREPARATION FOR AIR-EARTH INTERACTION	00008900
C		00008910
	1065 ZL3 = 2000.	00008920
	WINDF=2.0+WMAG	00008930
	DRAW=CD*WINDF	00008940
	EDV=ED/ZL3*WMAG/10.	00008950

C		00008960
C	DETERMINATION OF SURFACE TEMPERATURE	00008970
C		00008980
C		00008990
	1070 RH4=2.*WET*RH3/(WET+RH3)	00009000
	EG=10.** (8.4051-2353./TG)	00009010
	EG= AMIN1(EG,P4CB/1.662)	00009020
	QG=.622*EG/(P4CB-EG)	00009030
	DQG=5418.*QG/TG**2	00009040
	HHG=TG+CLH*QG*WET	00009050
	EDR=EDV/(EDV+DRAW)	00009060
	HH4=EDR*HH3+(1.-EDR)*HHG	00009070
	GAMG=CLH*DQG	00009080
	T4=(HH4-RH4*(CLH*QG-GAMG*TG))/(1.+RH4*GAMG)	00009090
	IF (T4*P10K/P4K.GT.TETA3) T4=TETA3*P4K/P10K	00009100
	Q4=RH4*(QG+DQG*(T4-TG))	00009110
	HH4=T4+CLH*Q4	00009120
C		00009130
C	PENETRATING AND LOW-LEVEL CONVECTION	00009140
C		00009150
	PC1=0.	00009160
	PC3=0.	00009170
	EX=0.	00009180
	IF (HH4 .LE. HH3S) GO TO 1077	00009190
	IF (HH3 .GT. HH1S) GO TO 1077	00009200
	EX = HH4-HH3S	00009210
	HH4P = HH4	00009220
	HH4 = HH3S	00009230
	IF (HH4P .LT. HH1S) GO TO 1076	00009240
	ETA = 1.	00009250
	TEMP1 = ETA*((HH3S-HH1S)/(1.+GAM1)+SS1-SS2)	00009260
	TEMP2 = ETA*(SS2-SS3) + (SS3-T4)	00009270
	TEMP = EDR*TEMP1+(1.+GAM3)*TEMP2	00009280
	IF (TEMP .LT. .001) TEMP=.001	00009290
	CONVP = RCNV*EX/TEMP	00009300
	PC1 = CONVP*TEMP1	00009310
	PC3 = CONVP * TEMP2	00009320
C		00009330
	1076 T4=T4-EX/(1.+RH4*GAMG)	00009340
	Q4=(HH4-T4)/CLH	00009350
C		00009360
	1077 R04=P4CB/(RGAS*T4)	00009370
	CSEN=CS4*R04*WINDF	00009380
	CEVA=CS*R04*WINDF	00009390

C		00009400
C	CLOUDINESS	00009410
C		00009420
	ICLOUD=1	00009430
	CL=0.	00009440
	CL1=0.	00009450
	CL2=0.	00009460
	CL3=0.	00009470
	CL7=0.	00009480
	CL=AMIN1(-1.3+2.6*RH3,1.)	00009490
	IF (CL.GT.0..OR.PC1.GT.0.) CL1=CL	00009500
	IF (PREC.GT.0..AND.CL1.EQ.0.) CL2=1.	00009510
	IF (EX.GT.0..AND.PC1.EQ.0.) CL3=CL	00009520
	=====	00009530
C		00009540
C		00009550
C		00009560
C		00009570
C		00009580
C		00009590
C		00009600
C		00009610
C		00009620
C		00009630
C		00009640
C		00009650
C		00009660
C		00009670
C		00009680
C	=====	00009690
	CL=AMAX1(CL1,CL2,CL3)	00009700
	IF (CL .GE. 1.) ICLOUD=3	00009710
	IF (CL .LT. 1. .AND. CL .GT. 0.) ICLOUD=2	00009720
C		00009730
C	ICLOUD=1 CLEAR, ICLOUD=2 PARTLY CLOUDY, ICLOUD=3 OVERCAST	00009740

C	LONG WAVE RADIATION	00009750
C		00009760
1080	Q3RB=AMAX1(Q3R,1.E-5)	00009770
	VAK=2.+ALOG(1.7188E-6/Q3RB)/ALOG(120./PL3)	00009780
	TEM1=.00102*PL3**2*Q3RB/VAK	00009790
	TEM2=TEM1*(P4/PL3)**VAK	00009800
	EFV3=TEM2-TEM1	00009810
	EFV2=TEM2-TEM1*(PL2/PL3)**VAK	00009820
	EFV1=TEM2-TEM1*(PL1/PL3)**VAK	00009830
	EFVT=TEM2-TEM1*(PTROP/PL3)**VAK	00009840
	EFV0=TEM2-TEM1*(120./PL3)**VAK+2.526E-5	00009850
	BLT=STB0*TTROP**4	00009860
	BL1=STB0*T1**4	00009870
	BL2=STB0*T2**4	00009880
	BL3=STB0*T3**4	00009890
	BL4=STB0*TG**4	00009900
C	LONG WAVE RADIATION	00009910
	ROC=0.	00009920
	R2C=0.	00009930
	R4C=0.	00009940
	URT=BLT*TRANS(EFV0-EFVT)	00009950
	UR2=BL2*TRANS(EFV0-EFV2)	00009960
	GO TO (1090,1090,2000), I CLOUD	00009970
1090	R00=0.82*(URT+(BL4-BLT)*(1.+TRANS(EFVT))/2.)	00009980
	R20=0.736*(UR2+(BL4-BL2)*(1.+TRANS(EFV2))/2.)	00009990
	R40=BL4*(0.6*SQR(TTRANS(EFV0))-0.1)	00010000
	IF (I CLOUD .EQ. 1) GO TO 2015	00010010
2000	IF (CL2 .LE. 0.) GO TO 2004	00010020
	CLT=CL2	00010030
	ROC=0.82*(URT+(BL2-BLT)*(1.+TRANS(EFVT-EFV2))/2.)*CLT	00010040
	R2C=0.736*UR2*CLT	00010050
	R2C=.5*R2C	00010060
	GO TO 2006	00010070
2004	IF (CL3 .LE. 0.) GO TO 2006	00010080
	CLT=CL3	00010090
	ROC=0.82*(URT+(BL3-BLT)*(1.+TRANS(EFVT-EFV3))/2.)*CLT	00010100
	R2C=0.736*(UR2+(BL3-BL2)*(1.+TRANS(EFV2-EFV3))/2.)*CLT	00010110
2006	IF (CL1 .LE. 0.) GO TO 2010	00010120
	CLM=AMAX1(CL1,0.)	00010130
C	IN PRESENT VERSION, CLM AND THIS TEM ARE ALWAYS ZERO	00010140
	TEM=0.	00010150
	IF (CLT .GT. 0.001) TEM=CLM/CLT	00010160
	ROC=0.82*(URT+(BL1-BLT)*(1.+TRANS(EFVT-EFV1))/2.)*CL1+ROC*TEM	00010170
	R2C=R2C*TEM	00010180
2010	R4C=0.85*(.25+.75*TRANS(EFV3))*(BL4-BL3)*CL	00010190
2015	R0=ROC+(1.-CL)*R00	00010200
	R2=R2C+(1.-CL)*R20	00010210
	R4=R4C+(1.-CL)*R40	00010220
	DIRAD=4.*STB0*TG**3	00010230



C		00010240
C	SURFACE ALBEDO	00010250
C		00010260
	IF (COSZ .LE. .01) GO TO 340	00010270
	SCOSZ=SO*COSZ	00010280
	ALS=.07	00010290
	IF (OCEAN) GO TO 335	00010300
	ALS=.14	00010310
	IF (LAT(J) .LT. SNOWN) GO TO 327	00010320
	CLAT=(LAT(J)-SNOWN)*CONRAD	00010330
	GO TO 330	00010340
327	IF (LAT(J) .GT. SNOWS) GO TO 328	00010350
	CLAT=(SNOWS-LAT(J))*CONRAD	00010360
	ALS=.45*(1.+(CLAT-10.)**2)/((CLAT-30.)**2+(CLAT-10.)**2)	00010370
	GO TO 335	00010380
328	IF (LAND) GO TO 335	00010390
	CLAT=0.0	00010400
330	ALS=.4*(1.+(CLAT-5.)**2)/((CLAT-45.)**2+(CLAT-5.)**2)	00010410
C		00010420
C	SOLAR RADIATION	00010430
C		00010440
335	ALAO=AMIN1(1.,.085-.247*ALOG10(COSZ/COLMR))	00010450
	SA=.349*SCOSZ	00010460
	SS=SCOSZ-SA	00010470
	ASOT=SA*TRSW((EFV0-EFV1)/COSZ)	00010480
	AS2T=SA*TRSW((EFV0-EFV2)/COSZ)	00010490
	FS2C=0.	00010500
	FS4C=0.	00010510
	S4C=0.	00010520
	GO TO (336,336,337), ICLOUD	00010530

C	CLEAR	
336	FS20=AS2T	00010540
	FS40=SA*TRSW(EFV0/COSZ)	00010550
	S40=(1.-ALS)*(FS40+(1.-ALAO)/(1.-ALAO*ALS)*SS)	00010560
	IF (ICLOUD.EQ. 1) GO TO 341	00010570
C	LARGE SCALE CLOUD	00010580
337	IF (CL2.LE. 0.) GO TO 338	00010590
	CLT=CL2	00010600
	FS2C=AS2T*CLT	00010610
	TEMS=SA*(1.-ALC2)*TRSW((EFV0-EFV2)/COSZ+1.66*(EFVC2+EFV3))	00010620
	FS4C=(TEMS+ALC2*AS2T)*CLT	00010630
	ALAC=ALC2+ALAO-ALC2*ALAO	00010640
	S4C=(1.-ALS)*(TEMS/(1.-ALC2*ALS)+(1.-ALAC)/(1.-ALAC*ALS)*SS)*CLT	00010650
	GO TO 339	00010660
C	LOW LEVEL CLOUD	00010670
338	IF (CL3.LE. 0.) GO TO 339	00010680
	CLT=CL3	00010690
	FS2C=AS2T*CLT	00010700
	TEMU=(EFV0-EFV3)/COSZ	00010710
	TEMS=SA*(1.-ALC3)*TRSW(TEMU+1.66*(EFVC3+EFV3))	00010720
	FS4C=(TEMS+ALC3*SA*TRSW(TEMU))*CLT	00010730
	ALAC=ALC3+ALAO-ALC3*ALAO	00010740
	S4C=(1.-ALS)*(TEMS/(1.-ALC3*ALS)+(1.-ALAC)/(1.-ALAC*ALS)*SS)*CLT	00010750
C	THICK CLOUD	00010760
339	IF (CL1.LE. 0.) GO TO 341	00010770
	CLM=AMAX1(CLT-CL1,0.)	00010780
C	IN PRESENT VERSION, CLM AND THIS TEM ARE ALWAYS ZERO	00010790
	TEM=0.	00010800
	IF (CLT.GT. 0.) TEM=CLM/CLT	00010810
	TEMU=(EFV0-EFV1)/COSZ	00010820
	TEMB=ALC1*TRSW(TEMU)*SA*CL1	00010830
	FS2C=SA*(1.-ALC1)*TRSW(TEMU+1.66*(EFVC1+EFV3))*CL1+TEMB+FS2C*TEM	00010840
	TEMS=SA*(1.-ALC1)*TRSW(TEMU+1.66*(EFVC1+EFV3))	00010850
	FS4C=TEMS*CL1+TEMB+FS4C*TEM	00010860
	ALAC=ALC1+ALAO-ALC1*ALAO	00010870
	S4C=(1.-ALS)*(TEMS/(1.-ALC1*ALS)	00010880
	X + (1.-ALAC)/(1.-ALAC*ALS)*SS)*CL1+S4C*TEM	00010890
C	MEAN CONDITION	00010900
341	FS2=FS2C+(1.-CL)*FS20	00010910
	FS4=FS4C+(1.-CL)*FS40	00010920
	S4=S4C+(1.-CL)*S40	00010930
	AS1=AS0T-FS2	00010940
	AS3=FS2-FS4	00010950
	GO TO 345	00010960
340	S4=0.0	00010970
	AS3=0.0	00010980
	AS1=0.0	00010990
		00011000

C		00011010
C	COMPUTATION OF GROUND TEMPERATURE	00011020
C		00011030
345	TGR=TG	00011040
	IF (OCEAN) GO TO 347	00011050
	BRA0=S4-R4	00011060
	TEM=0.	00011070
	IF (ICE.AND.222.LT.0.1) TEM=CTID/HICE	00011080
	A1=CSEN*(T4+CLH*(Q4+WET*(DOG*TG-QG)))	00011090
	A2=BRAD+4.*BL4+TEM*TICE	00011100
	B1=CSEN*(1.+CLH*DOG*WET)	00011110
	B2=D1RAD+TEM	00011120
	TGR=(A1+A2)/(B1+B2)	00011130
	IF (LAND.OR.TGR.LT.TICE) GO TO 346	00011140
	TGR=TICE	00011150
346	DR4=D1RAD*(TGR-TG)	00011160
	R4=R4+DR4	00011170
	R2=R2+.8*(1.-CL)*TRANS(EFV2)*OR4	00011180
	RO=RO+.8*(1.-CL)*TRANS(EFVT)*DR4	00011190
347	GT(J,1)=TGR	00011200
C		00011210
C	SENSIBLE HEAT (LY/DAY) AND EVAPORATION (GM/CM**2/SEC)	00011220
C		00011230
	E4=CEVA*(WET*(QG+DOG*(TGR-TG))-Q4)	00011240
	F4=CSEN*(TGR-T4)	00011250
	FK=RO4*FK1*WINOF	00011260
C		00011270
C	TOTAL HEATING AND MOISTURE BUDGET	00011280
C		00011290
	QN=(C1+C3+PC1+PC3)/CLH+PRFC-2.*E4*DTC3*GRAV/(SP*10.)	00011300
	Q3(J,1)=Q3(J,1)-QN	00011310
	IF (.NOT.LAND) GO TO 350	00011320
	RUNOFF=0.	00011330
	IF (QN.GT.0. .AND. WET.LT.1.) RUNOFF=.5*WET	00011340
	IF (QN.GT.0. .AND. WET.GE.1.) RUNOFF=1.	00011350
	WET = GW(J,1)+(1.-RUNOFF)*QN*5.*SP/GRAV/GWM	00011360
	IF (WET.GT.1.) WET = 1.	00011370
	IF (WET.LT.0.) WET = 0.	00011380
350	GW(J,1) = WET	00011390
C		00011400
	IF (Q3(J,1).LT.0.) Q3(J,1)=0.	00011410
	IF (KEY(31)) GO TO 360	00011420
351	H1=(AS1+R2-RO)*COE1*COLMR+C1+PC1	00011430
	H3=(AS3+R4-R2+F4)*COE1*COLMR+C3+PC3+PREC*CLM	00011440
	H(J,1,1)=0.5*(H1+H3)	00011450
	TEMP=0.5*(H1-H3)	00011460
	T(J,1,1)=T(J,1,1)+TEMP	00011470
	T(J,1,2)=T(J,1,2)-TEMP	00011480

C		00011490
C	SURFACE FRICTION	00011500
C		00011510
352	IF (J.EQ. 1) GO TO 358	00011520
	COLMR=4.*PM/(P(J,1)+P(J,1P1)+P(J-1,1)+P(J-1,1P1))	00011530
	DN 355 K=1,2	00011540
	K1=2*K	00011550
	K2=K1+1	00011560
	TEMP=Q(J,1,K1)-Q(J,1,K2)	00011570
	Q(J,1,K1)=Q(J,1,K1)-FM*TEMP*COLMR**2*DTC3	00011580
355	Q(J,1,K2)=Q(J,1,K2)+(FM*TEMP*COLMR-FK*(Q(J,1,K2)-.5*TEMP)*.7)	00011590
	+ *COLMR*DTC3	00011600
C		00011610
358	CONTINUE	00011620
C358	IF (MODOUT) GO TO 360	00011630
C		00011640
C	PACK FOR OUTPUT	00011650
C		00011660
	WW=SD(J,1)*3600./(2.0*DXYP(J))	00011670
	SCALE=SCALEU*COLMR	00011680
	KKK=IPK(IFIX(AS1*SCALE),IFIX(AS3*SCALE))	00011690
	TT(J,1,1)=XXX	00011700
	KKK=IPK(IFIX((R2-R0)*SCALE),IFIX((R4-R2)*SCALE))	00011710
	VT(J,1,2)=XXX	00011720
	KKK=IPK(IFIX(F4),IFIX(E4*100.*3600.*24.))	00011730
	TT(J,1,2)=XXX	00011740
	KKK=IPK(IFIX(T4*10.),IFIX(PREC*SCALEP*SP))	00011750
	Q3T(J,1)=XXX	00011760
	KKK=IPK(IFIX(EX*10.),IFIX((C1+C3+PC1+PC3)*SP*SCALEP/CLH))	00011770
	UT(J,1,2)=XXX	00011780
	KKK=IPK(IFIX(H1*100.*DAY/DTC3),IFIX(H3*100.*DAY/DTC3))	00011790
	PT(J,1)=XXX	00011800
	KKK=IPK(IFIX(S4/10.),IFIX(WW*100.))	00011810
	SD(J,1)=XXX	00011820
360	CONTINUE	00011830
370	CONTINUE	00011840
375	DN 377 I=1,IM	00011850
	DN 377 J=1,JM	00011860
377	H(J,1,1)=H(J,1,1)*DXYP(J)	00011870
C		00011880
	DN 390 I=1,IM	00011890
	IP1=MOD(I,IM)+1	00011900
	IM1=MOD(I+IMM2,IM)+1	00011910
	DN 380 J=2,JMM1	00011920
	TEMP=(H(J+1,IM1,1)+2.*H(J+1,1,1)+H(J+1,IP1,1)	00011930
	+ 2.*H(J,IM1,1) +4.*H(J,1,1)+2.*H(J,IP1,1)	00011940
	+ H(J-1,IM1,1)+2.*H(J-1,1,1)+H(J-1,IP1,1))/(16.*DXYP(J))	00011950
	T(J,1,1)=T(J,1,1)+TEMP	00011960
380	T(J,1,2)=T(J,1,2)+TEMP	00011970
	T(1,1,1)=T(1,1,1)+H(1,1,1)/DXYP(1)	00011980
	T(1,1,2)=T(1,1,2)+H(1,1,1)/DXYP(1)	00011990
	T(JM,1,1)=T(JM,1,1)+H(JM,1,1)/DXYP(JM)	00012000
390	T(JM,1,2)=T(JM,1,2)+H(JM,1,1)/DXYP(JM)	00012010
400	RETURN	00012020
	END	00012030

<u>S U B R O U T I N E</u>		
	* <u>COMP4</u>	00012040
/*		00012050
//	DD DISP=OLD,DSN=MFS727.AHN.COMMON	00012060
//	DD *	00012070
C		00012080
C		00012090
	DTC3=DT*FLOAT(NC3)	00012100
	SIG1=SIG(1)	00012110
	SIG3=SIG(2)	00012120
	DSIG=SIG3-SIG1	00012130
	JMM1=JM-1	00012140
	JMM2=JM-2	00012150
	IMM2=IM-2	00012160
	FIM=IM	00012170
	TSPD=DAY/DTC3	00012180
	IF(A.EQ.0.) GO TO 92	00012190
C		00012200
	DD 25 I=1,IM	00012210
	DD 20 J=2,JM	00012220
20	PV(J,I)=DXYP(J)*P(J,I)	00012230
25	PV(1,I)=DXYP(1)*P(1,I)	00012240
C		00012250
C	DIFFUSION OF MOMENTUM	00012260
C		00012270
	DD 30 I=1,IM	00012280
	IP1=MOD(I,IM)+1	00012290
	DD 30 J=2,JM	00012300
30	PU(J,I)=0.25*(PV(J,I)+PV(J-1,I)+PV(J,IP1)+PV(J-1,IP1))	00012310
	DD 90 K=2,5	00012320
	K1=K-MOD(K,2)	00012330
	FL=MOD(K,2)*2+1	00012340
	SIGCO=FL/2.	00012350
	DD 40 I=1,IM	00012360
	IP1=MOD(I,IM)+1	00012370
	DD 40 J=2,JM	00012380
40	PV(J,I)=SIGCO*(P(J,IP1)+P(J-1,IP1)-P(J,I)-P(J-1,I))	00012390
*	/(P(J,IP1)+P(J-1,IP1)+P(J,I)+P(J-1,I))	00012400
*	*(Q(J,I,K1)-Q(J,I,K1+1))	00012410
		00012420

```
DO 50 I=1,IM                                00012430
IM1=MOD(I+IMM2,IM)+1                        00012440
DO 50 J=2,JM                                00012450
TEMP=DTC3*(P(J,I)+P(J-1,I))*AXU(J)*DYU(J)/DXU(J)*0.5
*      *(Q(J,I,K)-Q(J,IM1,K)+PV(J,I)+PV(J,IM1)) 00012460
Q(J,I,K)=Q(J,I,K)-TEMP/PU(J,I)             00012470
50 Q(J,IM1,K)=Q(J,IM1,K)+TEMP/PU(J,IM1)     00012480
DO 60 I=1,IM                                00012490
IP1=MOD(I,IM)+1                             00012500
DO 60 J=2,JM                                00012510
60 PV(J,I)=SIGCO*(P(J,IP1)+P(J,I)-P(J-1,IP1)-P(J-1,I))
*      /(P(J,IP1)+P(J,I)+P(J-1,IP1)+P(J-1,I)) 00012520
*      *(Q(J,I,K1)-Q(J,I,K1+1))             00012530
DO 80 I=1,IM                                00012540
IP1=MOD(I,IM)+1                             00012550
DO 70 J=2,JMM1                              00012560
TEMP=DTC3*(P(J,IP1)+P(J,I))*AYU(J)*DXU(J)**3/DYU(J)*0.5
*      *((Q(J+1,I,K)+PV(J+1,I))/DXU(J+1)-(Q(J,I,K)-PV(J,I))/DXU(J)) 00012570
Q(J+1,I,K)=Q(J+1,I,K)-TEMP/(PU(J+1,I)*DXU(J+1)) 00012580
70 Q(J,I,K)=Q(J,I,K)+TEMP/(PU(J,I)*DXU(J))   00012590
TEMP=DTC3*P(JM,I)*AYU(JM)*DXU(JM)/DYU(JM)*(Q(JM,I,K)-PV(JM,I)) 00012600
Q(JM,I,K)=Q(JM,I,K)-TEMP/PU(JM,I)           00012610
TEMP=DTC3*P(2,I)*AYU(2)*DXU(2)/DYU(2)*(Q(2,I,K)-PV(2,I)) 00012620
80 Q(2,I,K)=Q(2,I,K)-TEMP/PU(2,I)           00012630
90 CONTINUE                                  00012640
92 CONTINUE                                  00012650
C                                              00012660
C      SMOOTHING LAPSE RATE                  00012670
C                                              00012680
99 DO 100 I=1,IM                             00012690
DO 100 J=1,JM                                00012700
100 TD(J,I)=(T(J,I,2)-T(J,I,1))*0.5/P(J,I)   00012710
DO 110 I=1,IM                                00012720
IM1=MOD(I+IMM2,IM)+1                        00012730
IP1=MOD(I,IM)+1                             00012740
DO 110 J=2,JMM1                              00012750
TDBAR = (TD(J+1,IM1)+2.*TD(J+1,I)+ TD(J+1,IP1)
2      +2.*TD(J,IM1) +4.*TD(J,I) +2.*TD(J,IP1) 00012760
3      + TD(J-1,IM1)+2.*TD(J-1,I)+ TD(J-1,IP1))/16. 00012770
TDSM=(TD(J,I)+(TDBAR-TD(J,I))/TSPD)*P(J,I) 00012780
TBAR=(T(J,I,2)+T(J,I,1))*0.5               00012790
T(J,I,1)=TBAR-TDSM                         00012800
110 T(J,I,2)=TBAR+TDSM                     00012810
RETURN                                       00012820
END                                           00012830
                                              00012840
                                              00012850
                                              00012860
                                              00012870
```

<u>S U B R O U T I N E</u>		
	* <u>INPUT</u>	00012880
/*		00012890
//	OD DISP=OLD,DSN=MES727.ABN.COMMON	00012900
//	DO *	00012910
C		00012920
	EQUIVALENCE (XXX,XXX)	00012930
	DIMENSION C1(800), IC1(800), IC(800), ALPH(8)	00012940
	EQUIVALENCE (OT(1,1,10),C1(1),IC1(1)), (C(1),IC(1))	00012950
	LOGICAL JUMP	00012960
	INTEGER KSET(32), BLANK/' '	00012970
	EQUIVALENCE (XLEV,ILEV)	00012980
C		00012990
C	INPUT PROGRAM	00013000
C		00013010
C	IF (KEY(11).OR. KEY(12)) GO TO 751	00013020
	PI=3.1415926	00013030
	SIG(1)=.25	00013040
	SIG(2)=.75	00013050
	DAYPYR=365.	00013060
	DECMAX=23.5/180.0*PI	00013070
	ROTPER=24.0	00013080
	EONX=173.0	00013090
	APHEL=183.0	00013100
	ECCN=0.0178	00013110
C	HISTORY FILE	00013120
	KTP=11	00013130
C	CHECKPOINT FILE	00013140
	LTP=1	00013150
C	DATA CARD IMAGE FILE	00013160
	INU=5	00013170
C	OUTPUT (MAP) STREAM	00013180
	MTP=6	00013190
C (1)		00013200
	READ (INU,50) ID,XLABL	00013210
C (2)		00013220
C		00013230
C	TRST=1. : RESTART USING NEW TAPE	00013240
C	TERM=0. : DO NOT TERMINATE OLD TAPE IF TRST=1.	00013250
	READ (INU,80) TAU10,TAU1H,TRST,TERM	00013260
	IF (TRST.NE.0.0) KTP=10	00013270
	TAU1=TAU10*24.+TAU1H	00013280
C (3)		00013290
	READ (INU,80) TAU0, TAU0, TAUH, TAU0, TAU0	00013300
	TAUE=24.0*TAUE	00013310
C (4)		00013320
	READ (INU,82) OTM, NCYCLE, NC3	00013330
C (5)		00013340
	READ (INU,10) JM, IM, OLAT	00013350
C (6)		00013360
	READ (INU,80) AX	00013370
C (7)		00013380
	READ (INU,80) FMX, ED, TCNV	00013390
		00013400

C (8)	READ (INU,80) RAO, GRAV, OAY	00013410
C (9)	READ (INU,80) RGAS, K&PA	00013420
C (10)	READ (INU,80) PSL, PTROP	00013430
C (11)	READ (INU,80) PSF	00013440
C (12)	FOR POLAR MAPS, LATITUDE OF INSCRIBED CIRCLE	00013450
C (13)	READ (INU,80) DLIC	00013460
	READ (INU,85) KSET	00013470
	DO 40 J=1,32	00013480
40	KEYS(J)=KSET(J).NE.BLANK	00013490
C		00013500
	OT=DTM*60.0	00013510
	A=AX*1.0E5	00013520
	FIM=IM	00013530
	DLAT=DLAT*PI/180.0	00013540
	DLOH=2.0*PI/FIM	00013550
	FM=FMX*0.00001	00013560
C		00013570
C		00013580
	RAD=RAD*1000.0	00013590
	OAY=OAY*3600.0	00013600
C		00013610
	CALL MAGFAC	00013620
	READ (INU,1199) MARK	00013630
123	TREAOY=.TRUE.	00013640
125	READ (KTP) TAUH, C1	00013650
	IF (TAUH .LT. 0.0) GO TO 135	00013660
	TAUH=TAUH	00013670
	TAUID=IFIX(TAUH/24.)	00013680
	TAUIM=TAUH-24.*TAUID	00013690
C	IF (KEY(9)) WRITE (MTP,9120) TAUID, TAUIM	00013700
	C(22) = C1(22)	00013710
	SOEDY = IC1(29)	00013720
	SDEYR = IC1(30)	00013730
	CALL OUTAPE(KTP,1)	00013740
	IF (TAUH-TAUIM) 125, 190, 190	00013750
135	BACKSPACE KTP	00013760
190	CONTINUE	00013770
	IF ((TRST.EQ.1.).AND.(TERM.EQ.0.)) GO TO 195	00013780
	TAUH=-ABS(TAUH)	00013790
	WRITE (KTP) TAUH,C1	00013800
	BACKSPACE KTP	00013810
195	CONTINUE	00013820
	IF (TRST.EQ.0.0) GO TO 202	00013830
	REWIND KTP	00013840
	KTP=11	00013850
	WRITE (KTP) TAUH,C	00013860
	CALL OUTAPE (KTP,2)	00013870
202	JUMP=.FALSE.	00013880
		00013890
		00013900
		00013910
		00013920
		00013930



C		00013940
205	CALL INIT2(MARK)	00013950
206	CALL INSDET	00013960
	IF (JUMP) GO TO 300	00013970
250	CONTINUE	00013980
C		00013990
	IF (KEY(-20)) TAU=24.	00014000
	TAU1=TAU	00014010
	WRITE (MTP,1200) ID,XLAHL	00014020
	WRITE (MTP,1201) TAU10,TAU1H,TRST,TAU1	00014030
	WRITE (MTP,1201) TAU0,TAU0,TAU0,TAU0,TAU0	00014040
	WRITE (MTP,1201) DTM,DLAT,AX,FMX,ED,TCNV	00014050
	WRITE (MTP,1201) RAD,GRV,DAY,REGAS,KAPA,PSL,PTROP,PSF,OLIC	00014060
	WRITE (MTP,1207) JM,IM,NCYCLE,NC3	00014070
	WRITE (MTP,1197) AX	00014080
	WRITE (MTP,1195) ED,TCNV	00014090
	WRITE (MTP,1196) FMX	00014100
C		00014110
300	TOFDAY=AMOD(TAU,RUTPER)	00014120
C	WRITE (2) GW,GT,TS,SN	00014130
C	REWIND 2	00014140
	RETURN	00014150
C		00014160
C		00014170
10	FORMAT (2I5,F10.0)	00014180
50	FORMAT (10A4)	00014190
57	FORMAT (12,A4,2F10.0,A4)	00014200
82	FORMAT (F10.0,2I5)	00014210
80	FORMAT (5F10.0)	00014220
85	FORMAT (32A1)	00014230
1195	FORMAT (6H0 FD=,F5.2,7H0 TCNV=,F5.0)	00014240
1196	FORMAT (6H0 FM=,F4.2,8H0(0.00001)	00014250
1197	FORMAT (6H0 A=,F4.2,9H0100000.0)	00014260
1199	FORMAT (2I3)	00014270
9120	FORMAT (1X,2F10.2)	00014280
9731	FORMAT ('1TAPE',14,' DOES NOT CONTAIN THE STARTING TIME')	00014290
9781	FORMAT ('0SWITCHING FROM TAPE ',12,' TO TAPE ',12)	00014300
1200	FORMAT (1H1,A4,2X,9A4)	00014310
1201	FORMAT (9(1X,E12.5))	00014320
1202	FORMAT (10(1X,15))	00014330
	END	00014340

C		00014350
	S U B R O U T I N E	00014360
	* MAGFAC	00014370
/*		00014380
//	DO OISP=OLO,OSN=MES727.ARN.COMMON	00014390
//	DO *	00014400
C		00014410
C	EQUAL LATITUDE OISTANCE PROJECTION	00014420
C		00014430
	JMM1=JM-1	00014440
	FJM=JM	00014450
	FJE=FJM/2.0+0.5	00014460
	ON 410 J=2,JMM1	00014470
	FJ=J	00014480
410	LATIJ)=DLAT*(FJ-FJE)	00014490
	LAT(1)=-PI/2.0	00014500
	LATIJM)=PI/2.0	00014510
C		00014520
	DO 415 J=2,JM	00014530
415	OYU(IJ)=RAO*(LAT(IJ)-LAT(IJ-1))	00014540
	OYU(1)=OYU(2)	00014550
	ON 420 J=1,JM	00014560
420	DXP(IJ)=RAO*COS(LAT(IJ))*DLON	00014570
C		00014580
	ON 430 J=2,JM	00014590
430	OXU(IJ)=0.5*(DXP(IJ)+DXP(IJ-1))	00014600
	OXU(1)=OXU(2)	00014610
	ON 440 J=2,JMM1	00014620
440	OYP(IJ)=0.5*(OYU(IJ+1)+OYU(IJ))	00014630
	OYP(1)=OYU(2)	00014640
	OYP(JM)=OYU(JM)	00014650
	ON 445 J=2,JMM1	00014660
445	DXYP(IJ)=0.5*(OXU(IJ)+OXU(IJ+1))*OYP(IJ)	00014670
	DXYP(1)=OXU(2)*OYP(1)*0.25	00014680
	DXYP(JM)=OXU(JM)*OYP(JM)*0.25	00014690
	DO 450 J=2,JMM1	00014700
450	F(IJ)=2.0*PI/DAY*(RAO/OXYP(IJ))*((COS(LAT(IJ-1))+COS(LAT(IJ)))*OXU(IJ)	00014710
	*-(COS(LAT(IJ))+COS(LAT(IJ+1)))*OXU(IJ+1))/2.0	00014720
	F(JM)=2.0*PI/DAY*(RAO/OXYP(JM))*((COS(LAT(JM-1))+COS(LAT(JM))	00014730
	*OXU(JM))/2.0	00014740
	F(1)=-F(JM)	00014750
C		00014760
C	USED IN COMP4 ONLY	00014770
	EXP1=4.0/3.0	00014780
	ON 42 J=1,JM	00014790
	AXU(IJ)=A*(OXU(IJ)/3.0E5)**EXP1	00014800
	AXV(IJ)=A*(OXV(IJ)/3.0E5)**EXP1	00014810
	AYU(IJ)=A*(OYU(IJ)/3.0E5)**EXP1	00014820
42	AYV(IJ)=A*(OYP(IJ)/3.0E5)**EXP1	00014830
	RETURN	00014840
	END	00014850

C		00014860
	<u>S U B R O U T I N E</u>	00014870
	* <u>INSOET</u>	00014880
/*		00014890
//	OD DISP=OLD,DSN=MES727,ARN,COMMON	00014900
//	OD *	00014910
	LOGICAL DCLK	00014920
C		00014930
	DO 411 J=1,JM	00014940
	SINL(J)=SIN(LAT(J))	00014950
411	COSL(J)=COS(LAT(J))	00014960
C		00014970
C	IF (KEY(11).OR.KEY(12)) GO TO 15	00014980
C		00014990
	INU=5	00015000
	READ (INU,7) CLKSW, RSETSW, LDAY, LYR	00015010
31	IF (RSETSW .NE. RESET) GO TO 14	00015020
	SDEOY=LDAY	00015030
	SDEYR=LYR	00015040
14	DCLK= .FALSE.	00015050
	CALL SOET	00015060
	IF (CLKSW .NE. OFF) DCLK= .TRUE.	00015070
	RETURN	00015080
C		00015090
15	OCLK= .FALSE.	00015100
	CALL SOET	00015110
	RETURN	00015120
C		00015130
7	FORMAT (A4,6X,A4,6X,13,7X,14)	00015140
C		00015150
	DATA RESET/4HRESE/, OFF/4HOFF /	00015160
C		00015170
	END	00015180

C									00015190
		<u>S U B R O U T I N E</u>							00015200
		* <u>SDET</u>							00015210
	/*								00015220
	//	DD	DISP=OLD,DSN=MES727.ARN.COMMON						00015230
	//	DD	*						00015240
C									00015250
			DIMENSION	ZMONTH(3,12),	MONTH(12)				00015260
			LOGICAL	DCLK					00015270
			MAXDAY=DAYPYR	+ 1.0E-2					00015280
			IF (DCLK)	SDEY=SDEY+1					00015290
			IF (SDEY .LE. MAXDAY)	GO TO 211					00015300
			SDEY=SDEY-MAXDAY						00015310
			SDEYR=SDEYR+1						00015320
211			JOYACC=0						00015330
			DO 251 L=1,12						00015340
			JOYACC=JOYACC+MONTH(L)						00015350
			IF (SDEY .LE. JOYACC)	GO TO 241					00015360
251			CONTINUE						00015370
			L=12						00015380
241			MONTHDY=MONTH(L)-JOYACC+SDEY						00015390
			AMONTH(1)=ZMONTH(1,L)						00015400
			AMONTH(2)=ZMONTH(2,L)						00015410
			AMONTH(3)=ZMONTH(3,L)						00015420
			DY=SDEY						00015430
			SEASON=(DY-EONX)/DAYPYR						00015440
			DIST=(DY-APHEL)/DAYPYR						00015450
C									00015460
C			EONX = JUNE 22						00015470
C			APHELION = JULY 1						00015480
C			ECCN= ORBITAL ECCENTRICITY						00015490
C									00015500
			DEC=DECMAX*COS(2.0*PI*SEASON)						00015510
			RSDIST=(1.0+ECCN*COS(2.0*PI*DIST))*2						00015520
			SIND=SIN(DEC)						00015530
			COSD=COS(DEC)						00015540
C									00015550
		DATA	ZMONTH/	JANUARY	FEBRUARY	MARCH	APRIL		00015560
X			MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	00015570
XER			NOVEMBER	DECEMBER/					00015580
		DATA	MONTH/31,28,31,30,31,30,31,31,30,31,30,31/						00015590
		RETURN							00015600
		END							00015610

C		00015620
	<u>S U B R O U T I N E</u>	00015630
	* <u>INIT1</u>	00015640
/*		00015650
//	DD DISP=OLD,DSN=MES727,ARN.COMMON	00015660
//	DD *	00015670
C		00015680
C		00015690
C	THIS SUBROUTINE IS FOR COLD START INITIAL CONDITION.	00015700
C		00015710
C	RETURN	00015720
C		00015730
	END	00015740
		00015750

C		00015760
	<u>S U B R O U T I N E</u>	00015770
	* <u>INIT2 (MARK1)</u>	00015780
/*		00015790
//	DD DISP=OLD,DSN=MES727,ARN.COMMON	00015800
//	DD *	00015810
	REAL METER	00015820
	DIMENSION HEIGHT (46)	00015830
	LOGICAL FAH	00015840
C		00015850
	INU = 5	00015860
	IF (MARK1 .EQ. 0) GO TO 71	00015870
C		00015880
C	READ UNIT CARD FOR GEOGRAPHY	00015890
C		00015900
75	READ (INU,110) TEMSCL	00015910
	IF (TEMSCL .EQ. FAREN) GO TO 86	00015920
	IF (TEMSCL .EQ. CENTIG) GO TO 46	00015930
	STOP 19121	00015940
86	FAH=.TRUE.	00015950
	GO TO 97	00015960
46	FAH=.FALSE.	00015970
	GO TO 97	00015980
19	WRITE (6,76)	00015990
	STOP	00016000
	97 CONTINUE	00016010

C		00016020
C	READ GEOGRAPHY DECK	00016030
C	OCEAN: SEA SURFACE TEMPERATURE	00016040
C	LAND: -64	00016050
C	SEA ICE OR LAND ICE: -96	00016060
C		00016070
	ON 15 IL=1,MARK1	00016080
	READ (INU,102) (TOPOG(J,IL),J=1,15),IL1,(TOPOG(J,IL),J=16,30),IL2	00016090
	X,(TOPOG(J,IL),J=31,46),IL3	00016100
	IF (IL1.NE.IL2.OR.IL2.NE.IL3.OR.IL1.NE.IL) GO TO 19	00016110
15	CONTINUE	00016120
	ON 23 IL=1,IM	00016130
	ON 23 JL=1,JM	00016140
	IF (TOPOG(JL,IL) .LE. -64.0) GO TO 23	00016150
	IF (FAH) TOPOG(JL,IL)=(TOPOG(JL,IL)-32.0)*5./9.	00016160
	TOPOG(JL,IL)=TOPOG(JL,IL)+273.0	00016170
23	CONTINUE	00016180
	CNST=GRAV*30.48	00016190
	MCST=1.	00016200
C		00016210
C	READ UNIT CARD FOR TOPOGRAPHY	00016220
C		00016230
	READ (INU,110) MSCL	00016240
	IF (MSCL .NE. FEET .AND. MSCL .NE. METER) GO TO 7A	00016250
	IF (MSCL .EQ. METER)MCST=39.39/120.	00016260
	CNST=CNST*MCST	00016270
	ON 10 I=1,MARK1	00016280
C		00016290
C	READ TOPOGRAPHY DECK	00016300
	READ (INU,101) (HEIGHT(J),J=1,25),IL1,(HEIGHT(J),J=26,40),IL2	00016310
	IF (IL1 .NE. IL2 .OR. IL1 .NE. 1) GO TO 19	00016320
	ON 20 J=1,JM	00016330
	IF (TOPOG(J,1)+64.0) 60,50,20	00016340
50	TOPOG(J,1)=-HEIGHT(J)*CNST	00016350
	GO TO 20	00016360
60	TOPOG(J,1)=-HEIGHT(J)*CNST+10.F5)	00016370
20	CONTINUE	00016380
10	CONTINUE	00016390
71	RETURN	00016400
78	WRITE (6,112) MSCL	00016410
	STOP 19122	00016420
C		00016430
101	FORMAT (25F3.0,1X,14/21F3.0,13X,14)	00016440
102	FORMAT (15F4.1,10X,12/15F4.1,10X,12/16F4.1,14X,12)	00016450
110	FORMAT (A4)	00016460
111	FORMAT (1H1,6X,2A6,40H NOT RECOGNIZED AS TEMPERATURE CONTROL. )	00016470
112	FORMAT (1H1,6X,2A6,36H NOT RECOGNIZED AS HEIGHT CONTROL. )	00016480
76	FORMAT(///69H GEOGRAPHY DATA SEQUENCE ERROR, RELOAD GEOGRAPHY DECK	00016490
	9 AND PUSH START.////)	00016500
	DATA FAREN/4HFAHR/,CENTIG/4HCENTI/,FEET/4HFEET/,METER/4HMETE/	00016510
C		00016520
	END	00016530

## 2. MAP PROGRAM LISTING

To facilitate the output of the primary dependent variables and auxiliary physical quantities, a number of routines for the production of analyzed maps have been prepared. Examples of these maps have been given in Chapters III and IV. The FORTRAN listing of the complete set of map routines is given below, with the cards in the program numbered sequentially for easy reference. Each of the map subroutines automatically computes the zonal average at each grid latitude, as well as the global average. The maps 2, 3, 4, 6, 8, 17, 18, 21, 27, and 28 may be produced for an arbitrary tropospheric  $\sigma$  or  $p$  surface by interpolation or extrapolation of the solutions at the basic levels  $\sigma = 1/4$  and  $\sigma = 3/4$ , while the other maps refer only to fixed levels, layers, or quantities.

It may be noted from the model description (see Chapter III) that while the primary dependent variables are computed each time step, the source or forcing terms (such as the diabatic heating) are computed every fifth time step. In order that any of the maps, whether involving a dependent variable and/or forcing term, may be prepared at any time selected for map output, portions of the subroutines OUTAPE, VPHI4, AVRX, and COMP 1 have been made part of the map program, a new subroutine MAPGEN has been written, and a substantial portion of the subroutine COMP 3 has also been incorporated. In this way those maps involving heating or precipitation, for example, are explicitly computed from the data at the time requested for map output.

The complete list of maps and the levels associated with their output (in  $\sigma$  coordinates) is shown below; examples of those maps marked by an asterisk (\*) are given in Chapter IV, with Map 5 given in Chapter III, Section F.

- \*Map 1: Smoothed sea-level pressure ( $\sigma = 1$ )
- \*Map 2: Zonal wind component ( $0 \leq \sigma \leq 1$ )
- \*Map 3: Meridional wind component ( $0 \leq \sigma \leq 1$ )
- \*Map 4: Temperature ( $0 \leq \sigma \leq 1$ )

- \* Map 5: Topography (sea-surface temperature, land elevation, ice distribution)
- \* Map 6: Geopotential height ( $0 \leq \sigma \leq 1$ )
- Map 7: Unsmoothed sea-level pressure ( $\sigma = 1$ )
- \* Map 8: Total diabatic heating ( $0 \leq \sigma \leq 1$ )
- \* Map 9: Large-scale precipitation rate
- \* Map 10: Sigma vertical velocity ( $\sigma = 1/2$ )
- \* Map 11: Relative humidity ( $\sigma = 3/4$ )
- \* Map 12: Precipitable water
- \* Map 13: Convective precipitation rate
- \* Map 14: Evaporation rate ( $\sigma = 1$ )
- \* Map 15: Sensible heat flux ( $\sigma = 1$ )
- \* Map 16: Lowest-level convection ( $\sigma = 1$ )
- Map 17: Wind direction angle ( $0 \leq \sigma \leq 1$ )
- Map 18: Wind direction vectors ( $0 \leq \sigma \leq 1$ )
- \* Map 19: Long-wave heating in layers ( $\sigma = 0$  to  $1/2$ ,  $\sigma = 1/2$  to  $1$ )
- \* Map 20: Short-wave absorption (heating) in layers ( $\sigma = 0$  to  $1/2$ ,  $\sigma = 1/2$  to  $1$ )
- Map 21: Wind magnitude ( $0 \leq \sigma \leq 1$ )
- \* Map 22: Surface short-wave absorption (heating) ( $\sigma = 1$ )
- \* Map 23: Surface air temperature ( $\sigma = 1$ )
- \* Map 24: Ground temperature ( $\sigma = 1$ )
- \* Map 25: Ground wetness ( $\sigma = 1$ )
- \* Map 26: Cloudiness (high, middle, low)
- Map 27: Pressure at sigma surfaces ( $0 \leq \sigma \leq 1$ )
- \* Map 28: Total convective heating in layers ( $\sigma = 0 - 1/2$ ,  $\sigma = 1/2 - 1$ )



- \* Map 29: Latent heating ( $\sigma = 1/2$  to 1)
- \* Map 30: Surface long-wave cooling ( $\sigma = 1$ )
- \* Map 31: Surface heat balance ( $\sigma = 1$ )

```

C*****00000010
C*****00000020
C*00000030
C*00000040
C*00000050
C*00000060
C*00000070
C*****00000080
/*00000090
// DD DISP=OLD,DSN=MES727.ABN.COMMON00000100
// DD *00000110
COMMON/CONT/ZM(46),SURF,LEV,ISL,NAME(13)00000120
COMMON /CDT/TAPIN00000130
DIMENSION MAP(99),SRF(99),SNT(99),ZM2(46)00000140
DATA JHLK/4H /00000150
DATA HCTP/'TAPE'/00000160
100 FORMAT (5E10.0)00000170
101 FORMAT (12,2E10.0,13A4)00000180
102 FORMAT (5(1X,F8.3))00000190
103 FORMAT (1X,12,2(1X,F8.3))00000200
104 FORMAT (1X,F8.2,2X,12,2X,F8.2,2X,13A4,2X,E13.5)00000210
105 FORMAT (2E10.0,A4)00000220
106 FORMAT (1X,F8.3,1X,F8.3,2X,A4)00000230
107 FORMAT (1H1)00000240
READ (5,105) TO,TEND,TAPIN00000250
WRITE (6,106) TO,TEND,TAPIN00000260
TOPDG(1,1)=-1.00000270
IF (TAPIN.NF.HCTP) READ (8) TOPDG00000280
TSA=TOPDG(1,1)00000290
TO=24.*TO00000300
TEND=24.*TEND00000310
DAY1=24.*3600.00000320
EJECT=0.00000330
I=00000340
200 READ (5,101) MAPNO,SURF00000350
WRITE (6,103) MAPNO,SURF00000360
I=I+100000370
MAP(I)=MAPNO00000380
IF (MAPNO.EQ.0) GO TO 23000000390
SRF(I)=SURF00000400
SNT(I)=SINT00000410
GO TO 20000000420
230 CONTINUE00000430
TI=0.00000440
250 READ (8) TAU,C00000450
DAY=DAY100000460
IF (TAU.EQ.TSA) GO TO 25000000470
NOOUT=00000480
T2=TAU/24.00000490
IF (EJECT.NE.0.0) EJECT=EJECT+1.00000500
IF (EJECT.EQ.2.0) PRINT 10700000510
WRITE (6,102) TAU,T200000520
IF (TAU.LT.0.0) GO TO 25000000530
CALL OUTAPE00000540
IF (TAU.LT.TO) GO TO 25000000550
IF (TAU.GT.TEND) CALL EXIT00000560
00000570

```

IF (TAU.LE.T1) GO TO 250	00000580
T1=TAU	00000590
I=1	00000600
IF (EJECT.NE.0.0) GO TO 270	00000610
CALL COMP3	00000620
PRINT 107	00000630
EJECT=1.0	00000640
270 MAPNO=MAP(I)	00000650
IF (MAPNO.EQ.0) GO TO 250	00000660
SURF=SRF(I)	00000670
SINT=SNT(I)	00000680
DO 275 J=1,13	00000690
275 NAME(J)=JBLK	00000700
CALL MOPGEN (MAPNO)	00000710
DO 290 J=1,JM	00000720
ZM2(J)=0.0	00000730
FCNT=0.0	00000740
DO 280 K=1,IM	00000750
IF (TOPOG(J,K).LT.1.0) GO TO 280	00000760
ZM2(J)=ZM2(J)+WORK2(J,K)	00000770
FCNT=FCNT+.0	00000780
280 CONTINUE	00000790
IF (FCNT.NE.0.0) ZM2(J)=ZM2(J)/FCNT	00000800
290 CONTINUE	00000810
WRITE(9)TAU,10,MAPNO,NAME,SURF,STAGI,STAGJ,SINT,WORK2,ZM,ZM2,ZMM	00000820
PRINT 104,T2,MAPNO,SURF,NAME	00000830
I=I+1	00000840
GO TO 270	00000850
END	00000860

```
SUBROUTINE OUTAPE
// 00 OISP=OLD,DSN=MES727.ABN.COMMON
//      OD *
COMMON /CDT/TAPIN
DATA BCTP/'TAPE'/
K=8
READ (K) P
READ (K) U
READ (K) V
READ (K) T
READ (K) Q3
IF (TAPIN.EQ.BCTP) READ (8) TOPOG
READ (K) PT
READ (K) GW
READ (K) TS
READ (K) GT
READ (K) SN
READ (K) TT
READ (K) Q3T
READ (K) SD
IF (TAPIN.NE.BCTP) RETURN
READ (K) H
READ (K) TD
RETURN
END
```

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00001080
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00001100
00001110
```

SUBROUTINE MOPGEN (MAPNO)	00001120
/*	00001130
// OD DISP=0LO,DSN=MES727,ABN.COMMON	00001140
// DD *	00001150
COMMON /SCTL/ RCTL(2), ICTL(10)	00001160
COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00001170
EQUIVALENCE (LEVEL,SURF)	00001180
LOGICAL LEV	00001190
MAPGEN=.TRUE.	00001200
LEV=.FALSE.	00001210
IF (SURF.LT.2.0) LEV=.TRUE.	00001220
C	00001230
GO TO (301,302,303,304,305,306,307,308,309,310	00001240
* ,311,312,313,314,315,316,317,318,319,320	00001250
* ,321,322,323,324,325,326,327,328,329,330,331),MAPNO	00001260
C	00001270
301 CALL MAP1	00001280
GO TO 410	00001290
302 CALL MAP2	00001300
GO TO 410	00001310
303 CALL MAP3	00001320
GO TO 410	00001330
304 CALL MAP4	00001340
GO TO 410	00001350
305 IF (KEY(18)) MAPGEN=.FALSE.	00001360
CALL MAP 5	00001370
GO TO 410	00001380
306 CALL MAP6	00001390
GO TO 410	00001400
307 CALL MAP7	00001410
GO TO 410	00001420
308 IF (NODUT.FQ.0) CALL COMP3	00001430
NODUT=1	00001440
CALL MAP8	00001450
GO TO 410	00001460
309 IF (NODUT.FQ.0) CALL COMP3	00001470
NODUT=1	00001480
CALL MAP9	00001490
GO TO 410	00001500
310 CALL MAP10	00001510
GO TO 410	00001520
311 CALL MAP 11	00001530
GO TO 410	00001540
312 CALL MAP12	00001550
GO TO 410	00001560

```

313 IF (NOUT.EQ.0) CALL COMP3
    NOUT=1
    CALL MAP13
    GO TO 410
314 IF (NOUT.EQ.0) CALL COMP3
    NOUT=1
    CALL MAP14
    GO TO 410
315 IF (NOUT.EQ.0) CALL COMP3
    NOUT=1
    CALL MAP15
    GO TO 410
316 IF (NOUT.EQ.0) CALL COMP3
    NOUT=1
    CALL MAP16
    GO TO 410
317 CALL MAP 2
    DO 3175 I=1,IM
    DO 3175 J=1,JM
3175 WORK1(J,I)=WORK2(J,I)
    CALL MAP 3
    CALL MAP 17
    GO TO 410
318 CALL MAP 2
    DO 3185 I=1,IM
    DO 3185 J=1,JM
3185 WORK1(J,I)=WORK2(J,I)
    CALL MAP 3
    CALL MAP 18
    GO TO 410
319 IF (NOUT.EQ.0) CALL COMP3
    NOUT=1
    CALL MAP19
    GO TO 410
320 IF (NOUT.EQ.0) CALL COMP3
    NOUT=1
    CALL MAP20
    GO TO 410
321 CALL MAP 2
    DO 3215 I=1,IM
    DO 3215 J=1,JM
3215 WORK1(J,I)=WORK2(J,I)
    CALL MAP 3
    CALL MAP 21
    GO TO 410
322 IF (NOUT.EQ.0) CALL COMP3
    NOUT=1
    CALL MAP22
    GO TO 410

```

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```
323 IF (NOUT.EQ.0) CALL COMP3
      NOUT=1
      CALL MAP23
      GO TO 410
324 CALL MAP24
      GO TO 410
325 CALL MAP 25
      GO TO 410
326 IF (NOUT.EQ.0) CALL COMP3
      NOUT=1
      CALL MAP26
      GO TO 410
327 CALL MAP27
      GO TO 410
328 IF (NOUT.EQ.0) CALL COMP3
      NOUT=1
      CALL MAP28
      GO TO 410
329 IF (NOUT.EQ.0) CALL COMP3
      NOUT=1
      CALL MAP29
      GO TO 410
330 IF (NOUT.EQ.0) CALL COMP3
      NOUT=1
      CALL MAP30
      GO TO 410
331 IF (NOUT.EQ.0) CALL COMP3
      NOUT=1
      CALL MAP 31
      GO TO 410
410 RETURN
C
      END
```

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00002070
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00002100
00002110
00002120
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00002140
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```

FUNCTION IPK(IL,IR)	00002390
INTEGER IHALF*2(2)	00002400
EQUIVALENCE (IHALF(1),IWC)	00002410
IHALF(1)=IL	00002420
IHALF(2)=IR	00002430
IPK=IWD	00002440
RETURN	00002450
ENTRY IRH(IPKW0)	00002460
IWD=IPKW0	00002470
IRH=IHALF(2)	00002480
RETURN	00002490
ENTRY ILH(IPKW0)	00002500
IWD=IPKW0	00002510
ILH=IHALF(1)	00002520
RETURN	00002530
END	00002540

FUNCTION VPHI4 (J,I)	00002550
C	00002560
/*	00002570
// DD DISP=OLD,DSN=MES727.ABN.COMMON	00002580
// DD *	00002590
VPHI4=0.	00002600
IF (TOPNG(J,I).LT. 1.0) VPHI4=AMOD(-TOPNG(J,I),10.E5)	00002610
C	00002620
RETURN	00002630
END	00002640
LOGICAL FUNCTION KEY(M)	00002650
LOGICAL KEYS*1(32)	00002660
COMMON /VKEYV/ KEYS	00002670
N=IABS(M)	00002680
KEY=KEYS(N)	00002690
IF (M.LT. 0) KEYS(N)=.FALSE.	00002700
RETURN	00002710
END	00002720



```

      S U B R O U T I N E
      *
      * MAP1
      // DD DISP=OLD,DSN=MES727.AHN.CIMMIN
      // DD *
      COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)
      LOGICAL LEV, STAGJ, STAGI, ISL
      DIMENSION NAMEL(13)
C
C   SEA LEVEL PRESSURE, MAP TYPE 1
C   L1=1
C   L2=2
C
C   FIM=1M
C   IMM2=1M-2
C   JMM1=JM-1
C   STAGJ=.FALSE.
C   STAGI=.FALSE.
C   SIG1=SIG(1)
C   SIG3=SIG(2)
C   FLR=.5*.1828/(30.48*(GRAV))
C
C   DD 110 I=1,NL
C   NAME(I)=NAMEL(I)
C
C   DD 118 J=1,JM
C   ZM(J)=0.0
C
C   DD 128 I=1,IM
C   DD 128 J=1,JM
C   PH14=VPH14(I,J,1)
C   PJ1=P(I,J,1)
C   TT4=ILH(Q3T(I,J,1))
C   T4=TT4/10.
C   EXTRAPOLATED SURFACE AIR TEMPERATURE
C   T1=T(I,J,1,L1)
C   T3=T(I,J,1,L2)
C   T4=.5*T3-.5*T1
C   RTM=RGAS*(T4+FLR*PH14)
C   ACC=(PJ1+PTRIP)*EXP(PH14/RTM)-PSL
C   ZM(J)=ZM(J)+ACC
128 WORK1(I,J,1)=ACC

```

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00002990
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00003130
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```

C	DO 148 I=1,IM	00003150
	IP1=MOD(I,IM)+1	00003160
	IM1=MOD(I+IMM2,IM)+1	00003170
	WORK2(JM,I)=WORK1(JM,I)	00003180
	WORK2(1,I)=WORK1(1,I)	00003190
	DO 148 J=2,JMM1	00003200
148	WORK2(J,I)=( WORK1(J+1,IM1)+2.*WORK1(J+1,I) + WORK1(J+1,IP1)	00003210
	, +2.*WORK1(J,IM1) +4.*WORK1(J,I) +2.*WORK1(J,IP1)	00003220
	, + WORK1(J-1,IM1)+2.*WORK1(J-1,I) + WORK1(J-1,IP1))/16.	00003230
C		00003240
	ZMM=0.0	00003250
	WTM=0.0	00003260
	DO 158 J=1,JM	00003270
	WTM=WTM + ABS(DXYP(J))	00003280
	ZM(J)=ZM(J)/FIM	00003290
158	ZMM=ZMM+ZM(J)*ABS(DXYP(J))	00003300
	ZMM=ZMM/WTM	00003310
	SPOL=ZM(1)	00003320
	NPOL=ZM(JM)	00003330
C		00003340
	DATA NAMEL/'SEA LEVEL PRESSURE SMOOTHED (MB-1000.)	00003350
	DATA NL/13/	*/ 00003360
	RETURN	00003370
C		00003380
	ENO	00003390
		00003400

<u>S U B R O U T I N E</u>		
	* <u>MAP2</u>	00003410
//	DO OISP=OLO,OSN=MES727.ABN.COMMON	00003420
//	DO *	00003430
	LOGICAL LEV, STAGJ, STAG1, ISL	00003440
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMF(13)	00003450
	EQUIVALENCE (SURF,SIGL)	00003460
	DIMENSION NAMEL(13)	00003470
C		00003480
C	EAST-WEST (U) WIND COMPONENT, MAP TYPE 2	00003490
C		00003500
	FM=1M	00003510
	STAGJ=.TRUE.	00003520
	STAG1=.TRUE.	00003530
C		00003540
	ON 110 I=1,NL	00003550
110	NAME(I)=NAMEL(I)	00003560
C		00003570
210	L1=1	00003580
	L2=2	00003590
	SIGL1=SIG(L1)	00003600
	SIGL2=SIG(L2)	00003610
	OSIG=1./(SIGL2-SIGL1)	00003620
C		00003630
	IF (LEV) GO TO 310	00003640
C		00003650
	PS=4.*(SURF-PTROP)	00003660
C		00003670
	ON 220 I=1,1M	00003680
	WORK2(I,1)=0.0	00003690
	IP1=MOD(1,1M) + 1	00003700
	ON 220 J=2,JM	00003710
	SIGPS=PS/(P(J,I) + P(J,IP1) + P(J-1,I) + P(J-1,IP1))	00003720
220	WORK2(J,I)=OSIG*((SIGPS-SIGL1)*U(J,I,L2)+(SIGL2-SIGPS)*U(J,I,L1))	00003730
	GO TO 410	00003740
C		00003750
310	OSIG1=(SIGL-SIGL1)*OSIG	00003760
	OSIG2=(SIGL2-SIGL)*OSIG	00003770
	ON 320 I=1,1M	00003780
	WORK2(I,1)=0.0	00003790
	ON 320 J=2,JM	00003800
320	WORK2(J,I)=OSIG1*U(J,I,L2)+U(J,I,L1)*OSIG2	00003810
		00003820

```
C
410  ZMM=0.0
      WTM=0.0
      ZM(1)=0.0
      DO 430 J=2,JM
        SUM=0.0
        DO 420 I=1,IM
          SUM=SUM+WORK2(J,I)
          CLAT=ABS(COS(.5*(LAT(J-1)+LAT(J))))
          ZM(J)=SUM/FIM
          WTM=WTM+CLAT
430   ZMM=ZMM+ZM(J)*CLAT
        ZMM=ZMM/WTM
        SPOL=ZM(2)
        NPOL=ZM(JM)
C
      DATA NAMEL/'EAST-WEST (U) WIND COMPONENT (M/SEC)
      DATA NL/13/
      RETURN
C
C
      END
```

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00003980  
00003990  
00004000  
00004010  
00004020  
00004030  
00004040

<u>S U B R O U T I N E</u>		
	* <u>MAP3</u>	00004050
//	DD DISP=ULD,DSN=MES727.ABN.COMMON	00004060
//	DD *	00004070
	LOGICAL LEV, STAGJ, STAG1, ISL	00004080
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00004090
	EQUIVALENCE (SURF,SIGL)	00004100
	DIMENSION NAMEL(13)	00004110
C		00004120
C	NORTH-SOUTH (V) WIND COMPONENT, MAP TYPE 3	00004130
C		00004140
	FIM=JM	00004150
	STAGJ=.TRUE.	00004160
	STAG1=.TRUE.	00004170
C		00004180
	DO 110 I=1,NL	00004190
110	NAME(I)=NAMEL(I)	00004200
C		00004210
210	L1=1	00004220
	L2=2	00004230
	SIGL1=SIG(L1)	00004240
	SIGL2=SIG(L2)	00004250
	USIG=1./(SIGL2-SIGL1)	00004260
C		00004270
	IF (LEV) GO TO 310	00004280
C		00004290
	PS=4.*(SURF-PTRIIP)	00004300
	DO 220 I=1,IM	00004310
	IP1=MOD(I,IM)+1	00004320
	DO 220 J=1,JM	00004330
	SIGPS=PS/(P(J,I) + P(J,IP1) + P(J-1,I) + P(J-1,IP1))	00004340
220	WORK2(J,I)=USIG*((SIGPS-SIGL1)*V(J,I,L2)+(SIGL2-SIGPS)*V(J,I,L1))	00004350
	GO TO 410	00004360
		00004370

C			00004380
310	DSIG1=(SIGL-SIGL1)*OSIG		00004390
	DSIG2=(SIGL2-SIGL)*OSIG		00004400
	DO 320 I=1,IM		00004410
	DO 320 J=1,JM		00004420
320	WORK2(J,I)=DSIG1*V(J,I,L2) + V(J,I,L1)*DSIG2		00004430
C			00004440
410	ZMM=0.0		00004450
	WTM=0.0		00004460
	DO 430 J=1,JM		00004470
	SUM=0.0		00004480
	DO 420 I=1,IM		00004490
420	SUM=SUM+WORK2(J,I)		00004500
	CLAT=ABS(COS(LAT(J)))		00004510
	ZM(J)=SUM/FIM		00004520
	WTM=WTM+CLAT		00004530
430	ZMM=ZMM+ZM(J)*CLAT		00004540
	ZMM=ZMM/WTM		00004550
	SPOL=ZM(1)		00004560
	NPOL=ZM(JM)		00004570
C			00004580
C			00004590
	DATA NAMEL/'NORTH-SOUTH (V) WIND COMPONENT (M/SEC)		00004600
	DATA NL/13/		00004610
C			00004620
	RETURN		00004630
	END		00004640

<u>S U B R O U T I N E</u>		
	* <u>MAP4</u>	00004650
//	DD DISP=OLD,DSN=MES727.ABN.COMMON	00004660
//	DD *	00004670
	LOGICAL LEV, STAGJ, STAGI, ISL	00004680
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00004690
	EQUIVALENCE (SURF,SIGL)	00004700
	DIMENSION NAMEL(13)	00004710
C		00004720
C	TEMPERATURE, MAP TYPE 4	00004730
C	VERTICAL INTERPOLATION IS WITH POTENTIAL TEMPERATURE	00004740
C	IN P**KAPPA SPACE.	00004750
		00004760
	FIM=IM	00004770
	STAGJ=.FALSE.	00004780
	STAGI=.FALSE.	00004790
C		00004800
	DO 110 I=1,NL	00004810
110	NAME(I)=NAMEL(I)	00004820
C		00004830
210	L1=1	00004840
	L2=2	00004850
	SIGL1=SIG(L1)	00004860
	SIGL2=SIG(L2)	00004870
	PSK=SURF**KAPPA	00004880
C		00004890
	DO 220 I=1,IM	00004900
	DO 220 J=1,JM	00004910
	SP=P(J,I)	00004920
	IF (LEV) PSK=(SIGL*SP+PTR(IP)**KAPPA	00004930
	PLIK=(SIGL1*SP+PTRUP)**KAPPA	00004940
	PL2K=(SIGL2*SP+PTRDP)**KAPPA	00004950
	TPOTL1=T(J,I,L1)/PLIK	00004960
	TPOTL2=T(J,I,L2)/PL2K	00004970
220	WORK2(J,I)=PSK/(PL2K-PLIK)*(TPOTL1*(PL2K-PSK) + (PSK-PLIK)*TPOTL2)	00004980
	+ TKEL	00004990
		00005000

```
C
C
410  ZMM=0.0
      WTM=0.0
      DO 430 J=1,JM
      SUM=0.0
      DO 420 I=1,IM
420  SUM=SUM+WORK2(J,I)
      CLAT=ABS(DXYP(J))
      ZM(J)=SUM/FIM
      WTM=WTM+CLAT
430  ZMM=ZMM+ZM(J)*CLAT
      ZMM=ZMM/WTM
      NPOL=ZM(JM)
      SPOL=ZM(1)
C
C
      DATA NAME/'TEMPERATURE (DEGREES CENTIGRADE)
      DATA NL/13/
      DATA TKEL/-273.1/
C
      RETURN
      END
```

00005010  
00005020  
00005030  
00005040  
00005050  
00005060  
00005070  
00005080  
00005090  
00005100  
00005110  
00005120  
00005130  
00005140  
00005150  
00005160  
00005170  
00005180  
00005190  
00005200  
00005210  
00005220  
00005230



<u>S U B R O U T I N E</u>		
	* <u>MAP5</u>	00005240
//	OD DISP=0LO,OSN=MES727.ABN.COMMUN	00005250
//	OD *	00005260
C		00005270
	LOGICAL LEV, STAGI,STAGJ, ISL	00005280
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00005290
	EQUIVALENCE (SURF,SIGL)	00005300
	DIMENSION NAME1(13),NAME2(13)	00005310
C		00005320
C	GEOGRAPHY, MAP TYPE 5	00005330
C		00005340
	FIM = IM	00005350
	FJM = JM	00005360
	STAGI=.FALSE.	00005370
	STAGJ=.FALSE.	00005380
	CNST=30.48*GkAV	00005390
C		00005400
	OD 110 I=1,NL	00005410
	NAME(I)=NAME1(I)	00005420
110	IF (.NOT.LEV) NAME(I)=NAME2(I)	00005430
C		00005440
	OD 220 I=1,IM	00005450
	OD 220 J=1,JM	00005460
	TG=TOPOG(J,I)	00005470
	IF (.NOT.LEV) GO TO 215	00005480
	IF (TG.LT.1.0) GO TO 205	00005490
	TG=TG-273.	00005500
	GO TO 220	00005510
205	IF (TG+10.E5.EQ.0.0) GO TO 220	00005520
210	TG=10.E5	00005530
	GO TO 220	00005540
215	IF (TG.GT.1.0) GO TO 210	00005550
	TG=-TG	00005560
	IF (TG.GT.9.E5) GO TO 218	00005570
	TG=TG/CNST	00005580
	GO TO 220	00005590
218	IF (TG.EQ.10.E5) GO TO 220	00005600
	TG=-(10.E5+(TG-10.E5)/CNST)	00005610
	GO TO 220	00005620
220	WORK2(J,I)=TG	00005630
C		00005640
410	WS=0.0	00005650
	WN=0.0	00005660
	OD 415 I=1,IM	00005670
	WS=WS+WORK2(I,I)	00005680
415	WN=WN+WORK2(JM,I)	00005690
	WS=WS/FIM	00005700
	WN=WN/FIM	00005710
	OD 420 I=1,IM	00005720
	WORK2(I,I)=WS	00005730
420	WORK2(JM,I)=WN	00005740
		00005750

C	ZMM=0.0	00005760
	WTM=0.0	00005770
	DO 450 J=1,JM	00005780
	SUM=0.0	00005790
	CI=0.0	00005800
	ZM(J)=0.0	00005810
	DO 430 I=1,IM	00005820
	W2=WORK2(J,I)	00005830
	IF (.NOT.LEV) GO TO 425	00005840
	IF (W2.GE.10.E5) GO TO 430	00005850
	CI=CI+1.0	00005860
	IF (W2.LT.0.0) GO TO 430	00005870
	SUM=SUM+W2	00005880
	GO TO 430	00005890
425	CI=CI+1.0	00005900
	IF (W2.GE.10.E5) GO TO 430	00005910
	IF (W2+10.E5.LE.0.0) W2=-(W2+10.E5)	00005920
	SUM=SUM+W2	00005930
430	CONTINUE	00005940
	CLAT=ABS(COS(LAT(J)))	00005950
	IF (CI.GT.0.0) ZM(J)=SUM/CI	00005960
	ZM(J)=SUM/FIM	00005970
	WTM=WTM+CLAT	00005980
450	ZMM=ZMM+ZM(J)*CLAT	00005990
	ZMM=ZMM/WTM	00006000
	SPOL=ZM(1)	00006010
	NPOL=ZM(JM)	00006020
C		00006030
	DATA NAME1/'TOPOGRAPHY (OCEAN TEMP, DEG CENT)	00006040
	DATA NAME2/'TOPOGRAPHY (SURFACE ELEVATION, HECTOFEET)	*/ 00006050
	DATA NL/13/	*/ 00006060
	RETURN	00006070
	END	00006080
		00006090

	S U B R O U T I N E	
	* MAP6	00006100
// DD	DISP=OLD,DSN=MES727,ARN,COMMON	00006110
// DD	*	00006120
	LOGICAL LEV, STAGJ, STAGI, ISL	00006130
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00006140
	EQUIVALENCE (SURF,SIGL)	00006150
	DIMENSION NAMEL(13)	00006160
		00006170
C	GEOPOTENTIAL HEIGHT SURFACE,	00006180
C	MAP TYPE 6	00006190
C		00006200
	IMM2=IM-2	00006210
	JMM1=JM-1	00006220
	STAG1= .FALSE.	00006230
	STAGJ= .FALSE.	00006240
	FIM=IM	00006250
	L1=1	00006260
	L2=2	00006270
	PSK=SURF**KAPA	00006280
	HR=RGAS/2.	00006290
	IMM2=IM-2	00006300
	SIGL1=SIG(L1)	00006310
	SIGL2=SIG(L2)	00006320
	DO 110 I=1,NL	00006330
110	NAME(I)=NAMEL(I)	00006340
	DO 220 I=1,IM	00006350
	IP1=MND(I,IM)+1	00006360
	IM1=MND(I+IMM2,IM)+1	00006370
	DO 220 J=1,JM	00006380
	SP=P(J,I)	00006390
	PL1=(SIGL1*SP+PTRDP)	00006400
	PL1K=PL1**KAPA	00006410
	PS1=(PL1-PTRDP)/PL1	00006420
	PL2=(SIGL2*SP+PTRDP)	00006430
	PL2K=PL2**KAPA	00006440
	PS2=(PL2-PTRDP)/PL2	00006450
	IF (LEV) PSK=(SIGL*SP+PTRDP)**KAPA	00006460
	PKDTK=KAPA*(PL2K-PL1K)*2.	00006470
	PL1KS=PL1K**2	00006480
	PL2KS=PL2K**2	00006490
	PSKS=PSK**2	00006500
	P1TP2=PL1K*PL2K*2.	00006510
	XT2=PS2+(PL2KS-P1TP2-PL1KS-2.*PSKS+4.*PL1K*PSK)/PKDTK/PL2K	00006520
	XT1=PS1+(PL2KS-P1TP2-PL1KS-4.*PL2K*PSK+2.*PSKS)/PKDTK/PL1K	00006530
	WNRK2(J,I)=.01*((XT1*T(J,I,L1)+XT2*T(J,I,L2))*HR+VPHI4(J,I))/GRAV	00006540
220		00006550

C		00006560
410	ZMM=0.0	00006570
	WTM=0.0	00006580
	DO 430 J=1,JM	00006590
	SUM=0.0	00006600
	CLAT=ABS(DXYP(J))	00006610
	DO 420 I=1,IM	00006620
420	SUM=SUM+WGRK2(J,I)	00006630
	ZM(J)=SUM/FIM	00006640
	WTM=WTM+CLAT	00006650
430	ZMM=ZMM+ZM(J)*CLAT	00006660
	ZMM=ZMM/WTM	00006670
	SPOL=ZM(1)	00006680
	NPOL=ZM(JM)	00006690
C		00006700
	DATA NAMEL/'GEOPOTENTIAL HEIGHT (MECTOMETERS)	1/ 00006710
	DATA NL/13/	00006720
	RETURN	00006730
	END	00006740

<u>S U R F A C E P R E S S U R E</u>		
<u>MAP 7</u>		
// DD	DISP=OLD,DSN=MES727,ABN.CIMM11N	00006750
//	DD *	00006760
C		00006770
	COMMON /COUT/ ZM(46),SURF,LFV,ISL,NAMF(13)	00006780
	LOGICAL LEV, STAGJ, STAGI, ISL	00006790
	DIMENSION NAMEL(13)	00006800
C	SURFACE PRESSURE, MAP TYPE 7	00006810
	L1=1	00006820
	L2=2	00006830
C		00006840
	F1M=1M	00006850
	F1M2=1M-2	00006860
	JMM1=JM-1	00006870
	STAGJ=.FALSE.	00006880
	STAGI=.FALSE.	00006890
	SIG1=SIG(1)	00006900
	SIG3=SIG(2)	00006910
	FLR=.5*.1828/(30.48*GRAV)	00006920
C		00006930
	DO 110 I=1,NL	00006940
110	NAMF(I)=NAMEL(I)	00006950
C		00006960
	ZMM=0.0	00006970
	DO 11A J=1,JM	00006980
11A	ZM(J)=0.0	00006990
C		00007000
	DO 12A I=1,1M	00007010
	1M1=MND(1+1MM2,1M)+1	00007020
	1P1=MND(1,1M1)+1	00007030
	DO 12A J=1,JM	00007040
	PH14=VPH14(J,1)	00007050
	PJ1=P(J,1)	00007060
C		00007070
	T14=1/LH(Q3T(J,1))	00007080
C		00007090
	T4=T14/10.	00007100
C	EXTRAPOLATED SURFACE AIR TEMPERATURE	00007110
	T1=T(J,1,L1)	00007120
	T3=T(J,1,L2)	00007130
	T4=1.5*T3-0.5*T1	00007140
	RTM=RGAS*(T4+FLR*PH14)	00007150
	ACC=(PJ1+PT400)*EXP(PH14/RTM)-PSL	00007160
	ZM(J)=ZM(J)+ACC	00007170
12A	WORK2(J,1)=ACC	00007180

C		00007190
C		00007200
	WTM=0.0	00007210
	DO 150 J=1,JM	00007220
	ZM(J)=ZM(J)/FIM	00007230
	WTM=WTM + ABS(DXYP(J))	00007240
	150 ZMM=ZMM+ZM(J)*ABS(DXYP(J))	00007250
C	ZMM IS GLOBAL MEAN SURFACE PRESSURE	00007260
	ZMM=ZMM/WTM	00007270
	SPOL=WORK2(1,1)	00007280
	NPOL=WORK2(JM,1)	00007290
C		00007300
	DATA NAMEL/'SEA LEVEL PRESSURE UNSMOOTHED (MB-1000.)	/ 00007310
	DATA NL/13/	00007320
	RETURN	00007330
C		00007340
	END	00007350

<u>S U B R O U T I N E</u>		
	* <u>MAPB</u>	00007360
//	DD 01SP=OLD,DSN=MES727.ABN.COMMON	00007370
//	DD *	00007380
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00007390
	LOGICAL LEV, STAGJ, STAGI, ISL	00007400
	EQUIVALENCE (SIGL,SURF)	00007410
	DIMENSION NAMEL(13)	00007420
C	TOTAL HEATING, MAP TYPE A	00007430
C		00007440
	DIMENSION HZ1(100),HZ3(100)	00007450
	FIM=JM	00007460
C		00007470
	STAGJ=.FALSE.	00007480
	STAGI=.FALSE.	00007490
	L1=1	00007500
	L2=2	00007510
	SIGL1=SIG(L1)	00007520
	SIGL2=SIG(L2)	00007530
	DSIG=1./((SIGL2-SIGL1))	00007540
	SURFMT=SURF-PTROP	00007550
	IF (LEV) SIGX=SIGL	00007560
C		00007570
	DD 110 I=1,NL	00007580
110	NAME(I)=NAMEL(I)	00007590
C		00007600
	DD 220 I=1,JM	00007610
	DD 220 J=1,JM	00007620
	IF (.NOT.LEV) SIGX=SURFMT/P(J,I)	00007630
	M1=ILH(PT(J,I))	00007640
	M1=M1/100.	00007650
	M3=IKH(PT(J,I))	00007660
	M3=M3/100.	00007670
	IF (J.NE.1) GO TO 220	00007680
	HZ1(J)=M1	00007690
	HZ3(J)=M3	00007700
220	WORK2(J,I)=DSIG*((SIGL2-SIGX)*M1 + (SIGX-SIGL1)*M3)	00007710
		00007720

C		00007730
	DO 110 J=1,JM	00007740
110	ZM(J)=0.0	00007750
C		00007760
	ZMM=0.0	00007770
	WTM=0.0	00007780
	DO 430 J=1,JM	00007790
	SUM=0.0	00007800
	CLAT=ABS(DXYP(J))	00007810
	DO 420 I=1,IM	00007820
420	SUM=SUM+WORK2(J,I)	00007830
	ZM(J)=SUM/FIM	00007840
	WTM=WTM+CLAT	00007850
430	ZMM=ZMM+ZM(J)*CLAT	00007860
	ZMM=ZMM/WTM	00007870
	SPOL=ZM(1)	00007880
	NPOL=ZM(JM)	00007890
C		00007900
	DATA NAMEL/'TOTAL HEATING (DEG CENT/DAY)	00007910
	DATA NL/13/	00007920
	RETURN	00007930
C		00007940
	END	00007950



<u>S U B R O U T I N E</u>		
<u>MAP9</u>		
//	DD DISP=OLD,DSN=MES727.AHN,COMMON	00007960
//	DD *	00007970
C		00007980
	LOGICAL LEV, STAG1, STAGJ, ISL	00007990
	DIMENSION NAMEL(13)	00008000
	COMMON /COUT/ ZM(46), SURF, LEV, ISL, NAME(13)	00008010
	EQUIVALENCE (SURF, SIGL)	00008020
C		00008030
C	LARGE SCALE PRECIPITATION, MAP TYPE 9	00008040
C		00008050
	FIM = IM	00008060
	FJM = JM	00008070
	STAG1=.FALSE.	00008080
	STAGJ=.FALSE.	00008090
C		00008100
	DD 110 I=1, NL	00008110
110	NAMEL(I)=NAMEL(I)	00008120
C		00008130
	DD 220 I=1, IM	00008140
	DD 220 J=1, JM	00008150
	PLSC=IRH(03T(J, I))	00008160
220	WORK2(J, I)=PLSC/10.	00008170
C		00008180
	ZMM=0.0	00008190
	WTM=0.0	00008200
	DD 450 J=1, JM	00008210
	SUM=0.0	00008220
430	DD 430 I=1, IM	00008230
	SUM=SUM + WORK2(J, I)	00008240
	CLAT=ABS(DXYP(J, I))	00008250
	ZM(J)=SUM/FIM	00008260
	WTM=WTM+CLAT	00008270
450	ZMM=ZMM+ZM(J)*CLAT	00008280
	ZMM=ZMM/WTM	00008290
	SPOL=ZM(1)	00008300
	NPOL=ZM(JM)	00008310
C		00008320
	DATA NAMEL/'LARGE SCALE PRECIPITATION (MM/DAY)	00008330
	DATA NL/13/	00008340
	RETURN	// 00008350
	END	00008360
		00008370
		00008380

<u>S U B R O U T I N E</u>		
<u>MAP10</u>		
/*		00008390
//	00 OISP=OLD,DSN=MES727.ABN.COMMON	00008400
//	DO *	00008410
	LOGICAL LEV, STAGJ, STAG1, ISL	00008420
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00008430
	EQUIVALENCE (SURF,SIGL)	00008440
	DIMENSION NAME1(13)	00008450
	DIMENSION CONM(46,72)	00008460
C		00008470
C	VERTICAL VELOCITY, MAP TYPE 10	00008480
C		00008490
	FIM=1M	00008500
	IMM2=1M-2	00008510
	JMM1=JM-1	00008520
	STAGJ=.FALSE.	00008530
	STAG1=.FALSE.	00008540
C		00008550
	ON 110 1=1,NL	00008560
110	NAME(1)=NAME1(1)	00008570
C		00008580
2149	L=1	00008590
2150	DO 2160 I=1,1M	00008600
	IP1=MND(I,1M)+1	00008610
	DO 2160 J=2,JMM1	00008620
	PU(J,I)=0.25*(OYU(J)*U(J,I,L)+DYU(J+1)*U(J+1,I,L))	00008630
2160	CONTINUE	00008640
C		00008650
	CALL AVRX(11)	00008660
C		00008670
	DO 2180 I=1,1M	00008680
	IP1=MND(I,1M)+1	00008690
	IM1=MND(I+IMM2,1M)+1	00008700
	DO 2170 J=2,JMM1	00008710
2170	PU(J,I)=PU(J,I)*(P(J,I)+P(J,IP1))	00008720
	DO 2180 J=2,JM	00008730
	PV(J,I)=0.25*OXU(J)*(V(J,I,L)+V(J,IM1,L))*(P(J,I)+P(J-1,I))	00008740
2180	CONTINUE	00008750
C		00008760
C	EQUIVALENT PU AT POLES. PV(1,I) IS USED AS A WORKING SPACE.	00008770
C		00008780
	VM1=0.0	00008790
	VM2=0.0	00008800
	DO 2185 I=1,1M	00008810
	VM1=VM1+PV(2,I)	00008820
2185	VM2=VM2+PV(JM,I)	00008830
	VM1=VM1/FIM	00008840
	VM2=VM2/FIM	00008850
	PV(1,1)=0.0	00008860
		00008870
		00008880

DO 2190 I=2,IM	00008890
2190 PV(1,I)=PV(1,I-1)+(PV(2,I)-VM1)	00008900
VM1=0.0	00008910
DO 2192 I=1,IM	00008920
2192 VM1=VM1+PV(1,I)	00008930
VM1=VM1/FIM	00008940
DO 2195 I=1,IM	00008950
2195 PU(1,I)=-(PV(1,I)-VM1)*3.0	00008960
PV(1,I)=0.0	00008970
DO 2200 I=2,IM	00008980
2200 PV(1,I)=PV(1,I-1)+(PV(JM,I)-VM2)	00008990
VM2=0.0	00009000
DO 2202 I=1,IM	00009010
2202 VM2=VM2+PV(1,I)	00009020
VM2=VM2/FIM	00009030
DO 2205 I=1,IM	00009040
2205 PU(JM,I)=(PV(1,I)-VM2)*3.0	00009050
DO 2400 I=1,IM	00009060
IM1=MOD(I+IMM2,IM)+1	00009070
DO 2400 J=1,JM	00009080
IF (J.EQ.1) CONVM=-PV(2,I)*0.5	00009090
IF (J.EQ.JM) CONVM=PV(JM,I)*0.5	00009100
IF (J.GT.1 .AND. J.LT.JM) CONVM=-(PU(J,I) -PU(J,IM1)	00009110
* +PV(J+1,I)-PV(J,I) )*0.5	00009120
IF (L.EQ.1) CONM(J,I)=CONVM	00009130
IF (L.EQ.2) PV(J,I)=CONVM	00009140
2400 CONTINUE	00009150
IF(L.EQ.2) GO TO 2410	00009160
L=2	00009170
GO TO 2150	00009180
2410 CONTINUE	00009190

C		00009200
C	CONM IS MASS CONVERGENCE AT L=1 AND PV IS THAT AT L=2.	00009210
C		00009220
2411	PH1=0.0	00009230
	PH2=0.0	00009240
	PH3=0.0	00009250
	PH4=0.0	00009260
	DO 2402 I=1,IM	00009270
	PH1=PH1+CONM(I,1)	00009280
	PH2=PH2+CONM(JM,1)	00009290
	PH3=PH3+PV(1,1)	00009300
2402	PH4=PH4+PV(JM,1)	00009310
	PH1=PH1/FIM	00009320
	PH2=PH2/FIM	00009330
	PH3=PH3/FIM	00009340
	PH4=PH4/FIM	00009350
	DO 2405 I=1,IM	00009360
	CONM(I,1)=PH1	00009370
	CONM(JM,1)=PH2	00009380
	PV(1,1)=PH3	00009390
2405	PV(JM,1)=PH4	00009400
	DO 2420 I=1,IM	00009410
	DO 2420 J=1,JM	00009420
	WW=CONM(J,1)-PV(J,1)	00009430
	WORK2(J,1)=3600.*WW/(2.0*DXYP(J))	00009440
2420	CONTINUE	00009450
C		00009460
410	ZMM=0.0	00009470
	WTM=0.0	00009480
	DO 430 J=1,JM	00009490
	SUM=0.0	00009500
	DO 420 I=1,IM	00009510
420	SUM=SUM+WORK2(I,J,1)	00009520
	CLAT=ABS(DXYP(J))	00009530
	ZM(J)=SUM/FIM	00009540
	WTM=WTM+CLAT	00009550
430	ZMM=ZMM+ZM(J)*CLAT	00009560
	ZMM=ZMM/WTM	00009570
	NPOL=ZM(JM)	00009580
	SPOL=ZM(1)	00009590
C		00009600
	DATA NAMEL/'SIGMA VERTICAL VELOCITY (MM/HR)	00009610
	DATA NL/13/	00009620
	RETURN	00009630
C		00009640
C		00009650
	END	00009660

S U B R O U T I N E	00009670
*                   AVRX(K)	00009680
/*	00009690
// OD DISP=OLD,DSN=MFS727,ARN.C(IMM(1N	00009700
//    OD *	00009710
C    THIS SUBROUTINE USES UT(1,1,1) AS A WORKING SPACE	00009720
C	00009730
JMM1=JM-1	00009740
IMM2=IM-2	00009750
JE=JM/2+1	00009760
OEFF=DYP(JE)	00009770
OD 150 J=2,JMM1	00009780
ORAT=OEFF/DXP(J)	00009790
IF (ORAT .LT. 1.) GO TO 150	00009800
ALP=0.125*(ORAT-1.)	00009810
NM=ORAT	00009820
FNM=NM	00009830
ALPHA=ALP/FNM	00009840
OD 150 N=1,NM	00009850
OD 120 I=1,IM	00009860
IP1=MOD(I,IM)+1	00009870
IM1=MOD(I+IMM2,IM)+1	00009880
120 UT(1,1,1)=QT(J,I,K)+ALPHA*(QT(J,IP1,K)+QT(J,IM1,K)-2.*QT(J,I,K))	00009890
OD 130 I=1,IM	00009900
130 QT(J,I,K)=UT(1,1,1)	00009910
150 CONTINUE	00009920
C	00009930
RETURN	00009940
END	00009950

```

      *      S U B R O U T I N E
      *      MAP11
/*
// OD OISP=OLD,OSN=MES727,AHN.COMMON
//      DD      *
      LOGICAL LEV, STAGI,STAGJ, ISL
      COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)
      EQUIVALENCE (SURF,SIGL)
      DIMENSION NAMEL(13)
C
C      RELATIVE HUMIDITY, MAP TYPE 11
C
      FIM = JM
      FJM = JM
      STAGI=.FALSE.
      STAGJ=.FALSE.
C
      DO 110 I=1,NL
110  NAME(I)=NAMEL(I)
C
      DO 220 I=1,IM
      DO 220 J=1,JM
      ES3 = 10.0**((R.4051-2353.0/T(J,I,2))
      P3CB = (.75*P(J,I)+PTR(P))/10.0
      QS3 = .622*ES3/(P3CB-ES3)
      Q3R = Q3(J,I)
      RH3 = Q3R/QS3
220  WORK2(J,I) = RH3*100.
C
410  WS=0.0
      WN=0.0
      DO 415 I=1,IM
      WS=WS+WORK2(I,I)
415  WN=WN+WORK2(JM,I)
      WS=WS/FJM
      WN=WN/FJM
      DO 420 I=1,IM
      WORK2(I,I)=WS
420  WORK2(JM,I)=WN

```

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00009960
00009970
00009980
00009990
00010000
00010010
00010020
00010030
00010040
00010050
00010060
00010070
00010080
00010090
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00010110
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00010170
00010180
00010190
00010200
00010210
00010220
00010230
00010240
00010250
00010260
00010270
00010280
00010290
00010300
00010310
00010320
00010330
00010340

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C	ZMM=0.0	00010350
	WTM=0.0	00010360
	00 450 J=1,JM	00010370
	SUM=0.0	00010380
	00 430 I=1,IM	00010390
430	SUM=SUM + WORK2(J,I)	00010400
	CLAT=ABS(DXYP(J))	00010410
	ZM(J)=SUM/FIM	00010420
	WTM=WTM+CLAT	00010430
450	ZMM=ZMM+ZM(J)*CLAT	00010440
	ZMM=ZMM/WTM	00010450
	SPOL=ZM(1)	00010460
	NPOL=ZM(JM)	00010470
C		00010480
	DATA NAME/'RELATIVE HUMIDITY (PERCENT)	00010490
	DATA NL/13/	/ 00010500
	RETURN	00010510
	END	00010520
		00010530

<u>S U B R O U T I N E</u>		
* <u>MAP12</u>		
/*		00010540
// DD DISP=OLD,DSN=MES727.ABN.COMMON		00010550
// DD *		00010560
LOGICAL LEV, STAGI,STAGJ, ISL		00010570
COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)		00010580
EQUIVALENCE (SURF,SIGL)		00010590
DIMENSION NAMEL(13)		00010600
C		00010610
C	PRECIPITABLE WATER IN CM, MAP TYPE 12	00010620
C		00010630
	FIM = IM	00010640
	STAGI=.FALSE.	00010650
	STAGJ=.FALSE.	00010660
C		00010670
	DO 110 I=1,NL	00010680
110	NAME(I)=NAMEL(I)	00010690
C		00010700
	DO 220 I=1,IM	00010710
	DO 220 J=1,JM	00010720
220	WORK2(J,I) = Q3(J,I)*P(J,I)*0.5*(10.0/GRAV)	00010730
C		00010740
410	WS=0.0	00010750
	WN=0.0	00010760
	DO 415 I=1,IM	00010770
	WS=WS+WORK2(I,I)	00010780
415	WN=WN+WORK2(JM,I)	00010790
	WS=WS/FIM	00010800
	WN=WN/FIM	00010810
	DO 420 I=1,IM	00010820
	WORK2(I,I)=WS	00010830
420	WORK2(JM,I)=WN	00010840
C		00010850
	ZMM=0.0	00010860
	WTM=0.0	00010870
	DO 450 J=1,JM	00010880
	SUM=0.0	00010890
	DO 430 I=1,IM	00010900
430	SUM=SUM + WORK2(J,I)	00010910
	CLAT=ABS(DXYP(J))	00010920
	ZM(J)=SUM/FIM	00010930
	WTM=WTM+CLAT	00010940
450	ZMM=ZMM+ZM(J)*CLAT	00010950
	ZMM=ZMM/WTM	00010960
	SPOL=ZM(1)	00010970
	NPOL=ZM(JM)	00010980
C		00010990
	DATA NAMEL/'PRECIPITABLE WATER (CM)	00011000
	DATA NL/13/	00011010
	RETURN	00011020
	END	00011030
		00011040
		00011050



<u>S U B R O U T I N E</u>		
<u>MAP13</u>		
/*		00011060
// DD DISP=OLD,DSN=MES727.ABN.COMMON		00011070
// DD *		00011080
	LOGICAL LEV, STAGI,STAGJ, ISL	00011090
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMF(13)	00011100
	EQUIVALENCE (SURF,SIGL)	00011110
	DIMENSION NAMEL(13)	00011120
C		00011130
C	CONVECTIVE PRECIPITATION (MM/DAY) MAP TYPE 13	00011140
C		00011150
	STAGI=.FALSE.	00011160
	STAGJ=.FALSE.	00011170
	FIM = 1M	00011180
C		00011190
	DO 110 I=1,NL	00011200
110	NAME(I)=NAMEL(I)	00011210
C		00011220
	DO 250 I=1,IM	00011230
	DO 250 J=1,JM	00011240
	CP=1RH(UT(J,1,2))	00011250
250	WORK2(J,1)=CP/10.	00011260
C		00011270
	WS=0.0	00011280
410	WN=0.0	00011290
	DO 415 I=1,IM	00011300
	WS=WS+WORK2(I,1)	00011310
415	WN=WN+WORK2(JM,1)	00011320
	WS=WS/FIM	00011330
	WN=WN/FIM	00011340
	DO 420 I=1,IM	00011350
	WORK2(I,1)=WS	00011360
420	WORK2(JM,1)=WN	00011370
C		00011380
	ZMM=0.0	00011390
	WTM=0.0	00011400
	DO 450 J=1,JM	00011410
	SUM=0.0	00011420
	DO 430 I=1,IM	00011430
430	SUM=SUM + WORK2(I,J)	00011440
	CLAT=ABS(DXYP(J))	00011450
	ZM(J)=SUM/FIM	00011460
	WTM=WTM+CLAT	00011470
450	ZMM=ZMM+ZM(J)*CLAT	00011480
	ZMM=ZMM/WTM	00011490
	SPOL=ZM(1)	00011500
	NPOL=ZM(JM)	00011510
C		00011520
	DATA NAMEL/'CONVECTIVE PRECIPITATION (MM/DAY)	00011530
	DATA NL/13/	00011540
	RETURN	00011550
	END	00011560
		00011570
		00011580

```

      *      S U B R O U T I N E
      *      MAP14
/*
// OD DISP=0LO,DSN=MES727.ABN.COMMUN
//      OD      *
C
      LOGICAL LEV, STAGI,STAGJ, ISL
      COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)
      EQUIVALENCE (SURF,SIGL)
      DIMENSION NAME(13)
C
C      EVAPORATION (E4 IN MM/DAY), MAP TYPE 14
C
      STAGI=.FALSE.
      FIM=IM
      STAGJ=.FALSE.
      IMM1=IM-1
      IMM2=IM-2
      JMM1=JM-1
      JMM2=JM-2
      DO 110 I=1,NL
110      NAME(I)=NAMEL(I)
C
      DO 250 I=1,IM
      DO 250 J=1,JM
      E4=IRH(TT(J,I,2))
250      WORK2(J,I)=E4/10.
C
C
410      WS=0.0
      WN=0.0
      DO 415 I=1,IM
      WS=WS+WORK2(I,I)
415      WN=WN+WORK2(JM,I)
      WS=WS/FIM
      WN=WN/FJM
      DO 420 I=1,IM
      WORK2(I,I)=WS
420      WORK2(JM,I)=WN

```

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00011590
00011600
00011610
00011620
00011630
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00011670
00011680
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00011700
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00011800
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00011940
00011950
00011960
00011970

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C	ZMM=0.0	00011980
	WTM=0.0	00011990
	DO 450 J=1,JM	00012000
	SUM=0.0	00012010
	DO 430 I=1,IM	00012020
430	SUM=SUM + WORK2(J,I)	00012030
	CLAT=ABS(OXYP(J))	00012040
	ZM(J)=SUM/FIM	00012050
	WTM=WTM+CLAT	00012060
450	ZMM=ZMM+ZM(J)*CLAT	00012070
	ZMM=ZMM/WTM	00012080
	SPOL=ZM(1)	00012090
	NPOL=ZM(JM)	00012100
C	DATA NAMEL/'EVAPORATION (MM/DAY)	00012110
	DATA NL/13/	00012120
	RETURN	'/ 00012130
	END	00012140
		00012150
		00012160

<u>S U B R O U T I N E</u>		
<u>MAP15</u>		
/*		00012170
//	DD DISP=OLD,DSN=MES727,ARN,COMMON	00012180
//	DD *	00012190
		00012200
	DIMENSION NAMEL(13)	00012210
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00012220
	LOGICAL LEV, STAGJ, STAGI, ISL	00012230
C		00012240
C	SENSIBLE HEAT FLUX (F4 IN TENS OF CAL*CM**2*DAY**1) MAP 15	00012250
C		00012260
	STAGI=.FALSE.	00012270
	STAGJ=.FALSE.	00012280
	FIM=IM	00012290
	IMM1=IM-1	00012300
	IMM2=IM-2	00012310
	JMM1=JM-1	00012320
	JMM2=JM-2	00012330
	DD 110 I=1,NL	00012340
110	NAME(I)=NAMEL(I)	00012350
C		00012360
	DD 350 I=1,IM	00012370
	DD 350 J=1,JM	00012380
	F4=ILM(TT(J,I,2))	00012390
350	WORK2(J,I)=F4/10.	00012400
C		00012410
410	WS=0.0	00012420
	WN=0.0	00012430
	DD 415 I=1,IM	00012440
	WS=WS+WORK2(I,I)	00012450
415	WN=WN+WORK2(JM,I)	00012460
	WS=WS/FIM	00012470
	WN=WN/FIM	00012480
	DD 420 I=1,IM	00012490
	WORK2(I,I)=WS	00012500
420	WORK2(JM,I)=WN	00012510
C		00012520
	ZMM=0.0	00012530
	WTM=0.0	00012540
	DD 450 J=1,JM	00012550
	SUM=0.0	00012560
	DD 430 I=1,IM	00012570
430	SUM=SUM + WORK2(J,I)	00012580
	CLAT=ABS(DXYP(J))	00012590
	ZM(J)=SUM/FIM	00012600
	WTM=WTM+CLAT	00012610
450	ZMM=ZMM+ZM(J)*CLAT	00012620
	ZMM=ZMM/WTM	00012630
	SPOL=ZM(I)	00012640
	NPOL=ZM(JM)	00012650
C		00012660
	DATA NAMEL/'SENSIBLE HEAT FLUX (10 CAL/CM**2/DAY)	00012670
	DATA NL/13/	00012680
	RETURN	00012690
C		00012700
	END	00012710
		00012720

	<u>S U B R O U T I N E.</u>	
	MAP 16	
// DD	DISP=OLD,DSN=MES727.ABN.COMMON	00012730
// DD *		00012740
	LOGICAL LEV, STAGJ, STAGI, ISL	00012750
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00012760
	EQUIVALENCE (SURF,SIGL)	00012770
	DIMENSION NAMEL(13)	00012780
C		00012790
C	LOW LEVEL CONVECTION (DEG) MAP TYPE 16	00012800
C		00012810
	FIM=IM	00012820
	STAGJ=.FALSE.	00012830
	STAGI=.FALSE.	00012840
C		00012850
	DO 110 I=1,NL	00012860
110	NAME(I)=NAMEL(I)	00012870
C		00012880
	DO 220 I=1,IM	00012890
	DO 220 J=1,JM	00012900
	FLSC=1LW(UT(J,I,2))	00012910
220	WORK2(J,I)=FLSC/10.	00012920
C		00012930
	410 ZMM=0.0	00012940
	WTM=0.0	00012950
	DO 430 J=1,JM	00012960
	SUM=0.0	00012970
	DO 420 I=1,IM	00012980
420	SUM=SUM+WORK2(J,I)	00012990
	CLAT=ABS(DXYP(J))	00013000
	ZM(J)=SUM/FIM	00013010
	WTM=WTM+CLAT	00013020
430	ZMM=ZMM+ZM(J)*CLAT	00013030
	ZMM=ZMM/WTM	00013040
	NPOL=ZM(JM)	00013050
	SPOL=ZM(I)	00013060
C		00013070
	DATA NAMEL/'LOW LEVEL CONVECTION (DEG CENT)	00013080
	DATA NL/13/	00013090
C	RETURN	00013100
	END	00013110
		00013120
		00013130
		00013140

<u>S U R R O U T I N E</u>		
	* MAP 17	00013150
// 00	OISP=OLO,OSN=MES727.ABN.COMMON	00013160
//	DD *	00013170
	LOGICAL LEV, STAGJ, STAGI, ISL	00013180
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMF(13)	00013190
	EQUIVALENCE (SURF,SIGL)	00013200
	DIMENSION NAMEL(13)	00013210
C		00013220
C	WIND DIRECTION, MAP TYPE 17	00013230
C	(NORMALLY POLAR PROJECTED)	00013240
C		00013250
	P102=P1*.5	00013260
	P102T3=P102*3.	00013270
	P1T2=P1*2.	00013280
	RP1035=35./P1T2	00013290
C		00013300
	DO 220 I=1,IM	00013310
	DO 220 J=1,JM	00013320
	WU=WORK1(J,I)	00013330
	WV=WORK2(J,I)	00013340
	K=1	00013350
	IF (WU .GE. 0.) K=K+1	00013360
	IF (WV.EQ. 0.) GO TO (103,104),K	00013370
	IF (WV .GE. 0.) K=K+2	00013380
	IF (WU .EQ. 0.) K=K+4	00013390
	ANG=ATAN(WU/WV)	00013400
	GO TO (220,101,102,102,101,101,102,102), K	00013410
101	ANG=ANG+P1T2	00013420
	GO TO 220	00013430
102	ANG=ANG+P1	00013440
	GO TO 220	00013450
103	ANG=P102	00013460
	GO TO 220	00013470
104	ANG=P102T3	00013480
220	WORK2(J,I)=ANG*RP1035+1.0	00013490
		00013500

```
C
110 DO 110 I=1,NL
    NAME(I)=NAMEL(I)
    STAGJ=.TRUE.
    STAGI=.TRUE.
    FIM=IM
C
410 ZMM=0.0
    WTM=0.0
    DO 430 J=1,JM
        SUM=0.0
        DO 420 I=1,IM
            SUM=SUM+WORK2(J,I)
            CLAT=ABS(COS(LAT(J)))
            ZM(I)=SUM/FIM
            WTM=WTM+CLAT
430 ZMM=ZMM+ZM(I)*CLAT
        ZMM=ZMM/WTM
        SPOL=ZM(1)
        NPOL=ZM(JM)
C
    DATA NAMEL/'WIND DIRECTION
    DATA NL/13/
    RETURN
C
C
    END
```

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00013510
00013520
00013530
00013540
00013550
00013560
00013570
00013580
00013590
00013600
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00013670
00013680
00013690
00013700
00013710
00013720
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00013750
00013760
00013770
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<u>S U B R O U T I N E</u>		
	* MAP 10	00013780
//	DD DISP=OLD,DSN=MES727.ARN.COMMON	00013790
//	DD *	00013800
	LOGICAL LEV, STAGJ, STAGI, ISL	00013810
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAMF(13)	00013820
	EQUIVALENCE (SURF,SIGL)	00013830
	DIMENSION NAMEL(13)	00013840
C		00013850
C	MAP WIND DIRECTION, MAP TYPE 1A	00013860
C	(MEANINGFUL ON CLYNDRICAL PROJECTION ONLY)	00013870
C		00013880
	P102=P1*.5	00013890
	P102T3=P102*3.	00013900
	P1T2=P1*2.	00013910
	P0T1A=1A./P1	00013920
C		00013930
C		00013940
	DO 220 I=1,IM	00013950
	DO 220 J=1,JM	00013960
	WU=WORK1(J,I)/DXU(J)	00013970
	WV=WORK2(J,I)/DYV(J)	00013980
	IF (WU.EQ. 0. .AND. WV.EQ. 0.) WV=1.	00013990
	ANG=ATAN2(WU,WV)	00014000
	IF (ANG.LT. 0.) ANG=ANG+P1T2	00014010
220	WORK2(J,I)=AMOD(ANG+P0T1A+1A.,36.)	00014020
C		00014030
	DO 110 I=1,NL	00014040
110	NAME(I)=NAMEL(I)	00014050
	FIM=IM	00014060
	STAGJ=.TRUE.	00014070
	STAGI=.TRUE.	00014080
C		00014090
410	ZMM=0.0	00014100
	WTM=0.0	00014110
	DO 430 J=1,JM	00014120
	SUM=0.0	00014130
	DO 420 I=1,IM	00014140
420	SUM=SUM+WORK2(J,I)	00014150
	CLAT=ABS(COS(LAT(J)))	00014160
	ZM(J)=SUM/FIM	00014170
	WTM=WTM+CLAT	00014180
430	ZMM=ZMM+ZM(J)*CLAT	00014190
	ZMM=ZMM/WTM	00014200
	SPOL=ZM(1)	00014210
	NPOL=ZM(JM)	00014220
C		00014230
	DATA NAMEL/'MAP WIND DIRECTION	00014240
	DATA NL/13/	00014250
	RETURN	00014260
C		00014270
C		00014280
	END	00014290
		00014300



<u>S U B R O U T I N E</u>		
	* <u>MAP19</u>	00014310
//	OD OISP=OLO,DSN=MES727.ABN.COMMON	00014320
//	OD *	00014330
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00014340
	LOGICAL LEV, STAGJ, STAGI, ISL	00014350
	DIMENSION NAMEL(13)	00014360
	LOGICAL LHLF	00014370
C		00014380
C	LONG WAVE COOLING. MAP TYPE 19	00014390
C		00014400
	FIM=1M	00014410
	STAGJ=.FALSE.	00014420
	STAGI=.FALSE.	00014430
C		00014440
C		00014450
	LHLF= SURF .LT. .5	00014460
	OD 110 I=1,NL	00014470
110	NAME(I)=NAMEL(I)	00014480
	OD 118 J=1,JM	00014490
118	ZM(J)=0.0	00014500
C		00014510
	OD 150 I=1,IM	00014520
	OD 150 J=1,JM	00014530
	IF (LHLF) GO TO 125	00014540
	ACC=1RM(VT(J,1,2))	00014550
	ACC=ACC/100.	00014560
	GO TO 140	00014570
125	ACC=1LM(VT(J,1,2))	00014580
	ACC=ACC/100.	00014590
140	ZM(J)=ZM(J)+ACC	00014600
150	WORK2(J,1)=ACC	00014610
C		00014620
	ZMM=0.	00014630
	WTM=0.0	00014640
	OD 158 J=1,JM	00014650
	WTM=WTM + AHS(DXYP(J))	00014660
	ZM(J)=ZM(J)/FIM	00014670
158	ZMM=ZMM+ZM(J)*AHS(DXYP(J))	00014680
	ZMM=ZMM/WTM	00014690
	SPOL=ZM(1)	00014700
	NPOL=ZM(JM)	00014710
C		00014720
	DATA NAMEL/'LONG WAVE HEATING IN LAYERS (DEG CENT/DAY)	00014730
	DATA NL/13/	00014740
	RETURN	00014750
C		00014760
	END	00014770
		00014780

<u>S U B R O U T I N E</u>		
	* <u>MAP20</u>	00014790
// DD	DISP=OLD,OSN=MES727.ABN.COMMON	00014800
//	DD *	00014810
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00014820
C	ABSORPTION OF INSOLATION, MAP TYPE 20	00014830
	LOGICAL LEV, STAGJ, STAGI, ISL	00014840
	DIMENSION NAMEL(13)	00014850
	LOGICAL LMLF	00014860
C		00014870
	FIM=IM	00014880
	STAGJ=.FALSE.	00014890
	STAGI=.FALSE.	00014900
C		00014910
	LMLF= SURF .GT. .5	00014920
C		00014930
	DO 110 I=1,NL	00014940
110	NAME(I)=NAMEL(I)	00014950
C		00014960
	DO 118 J=1,JM	00014970
118	ZM(J)=0.	00014980
C		00014990
	DO 150 I=1,IM	00015000
	DO 150 J=1,JM	00015010
	IF (LMLF) GO TO 125	00015020
	ACC=1LM(ITT(J,I,1))	00015030
	ACC=ACC/100.	00015040
	GO TO 140	00015050
125	ACC=1RM(ITT(J,I,1))	00015060
	ACC=ACC/100.	00015070
140	ZM(J)=ZM(J)+ACC	00015080
150	WORK2(J,I)=ACC	00015090
C		00015100
	ZMM=0.0	00015110
	WTM=0.0	00015120
	DO 158 J=1,JM	00015130
	WTM=WTM + ABS(OXYP(J))	00015140
	ZM(J)=ZM(J)/FIM	00015150
158	ZMM=ZMM+ZM(J)*ABS(OXYP(J))	00015160
	ZMM=ZMM/WTM	00015170
	SPOL=ZM(1)	00015180
	NPOL=ZM(JM)	00015190
C		00015200
	DATA NAMEL/'ABSORPTION OF INSOLATION IN LAYERS (DEG CENT/DAY) '	00015210
	DATA NL/13/	00015220
	RETURN	00015230
C		00015240
	ENO	00015250
		00015260

<u>S U B R O U T I N E</u>		
	* <u>MAP21</u>	00015270
// DD	DISP=OLD,DSN=MES727.ABN.COMM/N	00015280
//	DD *	00015290
	LOGICAL LEV, STAGJ, STAGI, ISL	00015300
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00015310
	EQUIVALENCE (SURF,SIGL)	00015320
	DIMENSION NAMEL(13)	00015330
C		00015340
C	WIND SPEED, MAP TYPE 21	00015350
C		00015360
	IMM2=IM-2	00015370
	JMM1=JM-1	00015380
C		00015390
C		00015400
	DO 110 I=1,NL	00015410
110	NAME(I)=NAMEL(I)	00015420
C		00015430
	STAGJ=.TRUE.	00015440
	STAGI=.TRUE.	00015450
C		00015460
	DO 330 I=1,IM	00015470
	DO 330 J=2,JM	00015480
	WIND=WORK2(J,I)**2+WORK1(J,I)**2	00015490
330	WORK2(J,I)=SQRT(WIND)	00015500
C		00015510
	FIM=IM	00015520
	ZMM=0.0	00015530
	WTM=0.0	00015540
	DO 430 J=2,JM	00015550
	SUM=0.0	00015560
	DO 420 I=1,IM	00015570
420	SUM=SUM+WORK2(J,I)	00015580
	CLAT=ABS(COS(.5*(LAT(J-1)+LAT(J))))	00015590
	ZM(J)=SUM/FIM	00015600
	WTM=WTM+CLAT	00015610
430	ZMM=ZMM+ZM(J)*CLAT	00015620
	ZMM=ZMM/WTM	00015630
	SPOL=ZM(2)	00015640
	NPOL=ZM(JM)	00015650
C		00015660
	DATA NAMEL/'MAGNITUDE OF THE VECTOR WIND (M/SEC)	00015670
	DATA NL/13/	// 00015680
	RETURN	00015690
C		00015700
	END	00015710
		00015720

	<u>S U B R O U T I N E</u>	
	* <u>MAP22</u>	
//	00 DISP=OLD,DSN=MES727.ABN,COMMON	00015730
//	DO *	00015740
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00015750
	LOGICAL LEV, STAGJ, STAGI, ISL	00015760
	DIMENSION NAMEL(13)	00015770
C		00015780
C	SURFACE INSOLATION MAP TYPE 22	00015790
C		00015800
	FIM=IM	00015810
	STAGJ=.FALSE.	00015820
	STAGI=.FALSE.	00015830
C		00015840
	DO 110 I=1,NL	00015850
110	NAME(I)=NAMEL(I)	00015860
C		00015870
	DO 150 J=1,JM	00015880
150	ZM(J)=0.0	00015890
C		00015900
	DO 275 I=1,IM	00015910
	DO 275 J=1,JM	00015920
	ACC=ILH(SD(J,I))	00015930
	ACC=ACC/10.	00015940
	ZM(J)=ZM(J)+ACC	00015950
275	WORK2(J,I)=ACC	00015960
C		00015970
	ZMM=0.0	00015980
	WTM=0.0	00015990
	DO 158 J=1,JM	00016000
	WTM=WTM + ABS(DXYP(J))	00016010
	ZM(J)=ZM(J)/FIM	00016020
158	ZMM=ZMM+ZM(J)*ABS(DXYP(J))	00016030
	ZMM=ZMM/WTM	00016040
	SPOL=ZM(1)	00016050
	NPOL=ZM(JM)	00016060
C		00016070
	DATA NAMEL/'SURFACE INSOLATION ABSORPTION (100 CAL/CM**2/DAY) '	00016080
	DATA NL/13/	00016090
	RETURN	00016100
C		00016110
	END	00016120
		00016130
		00016140

<u>S U B R O U T I N E</u>		
	* <u>MAP 23</u>	00016150
//	DD DISP=OLD,DSN=MES727.ABN.COMMON	00016160
//	DD *	00016170
	LOGICAL LEV, STAGJ, STAGI, ISL	00016180
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00016190
	EQUIVALENCE (SURF,SIGL)	00016200
	DIMENSION NAMEL(13)	00016210
C	SURFACE AIR TEMPERATURE, MAP TYPE 23	00016220
C		00016230
	FIM=IM	00016240
	STAGJ=.FALSE.	00016250
	STAGI=.FALSE.	00016260
C		00016270
	DD 110 I=1,NL	00016280
110	NAME(I)=NAMEL(I)	00016290
C		00016300
	DD 220 I=1,IM	00016310
	DD 220 J=1,JM	00016320
	TT4=1LM(Q3T(J,1))	00016330
220	WORK2(J,1)=TT4/10. - TICE	00016340
C		00016350
410	ZMM=0.0	00016360
	WTM=0.0	00016370
	DD 430 J=1,JM	00016380
	SUM=0.0	00016390
	DD 420 I=1,IM	00016400
420	SUM=SUM+WORK2(J,1)	00016410
	CLAT=ABS(DXYP(J))	00016420
	ZM(J)=SUM/FIM	00016430
	WTM=WTM+CLAT	00016440
430	ZMM=ZMM+ZM(J)*CLAT	00016450
	ZMM=ZMM/WTM	00016460
	NPOL=ZM(JM)	00016470
	SPOL=ZM(1)	00016480
C		00016490
	DATA TICE/273.1/	00016500
	DATA NAMEL/'SURFACE AIR TEMPERATURE (DEG CENT)	00016510
	DATA NL/13/	00016520
C		00016530
	RETURN	00016540
	END	00016550
		00016560

	<u>S U B R O U T I N E</u>	00016570
	* <u>MAP24</u>	00016580
//	DO DISP=NL0,OSN=MES727.ABN.COMMON	00016590
//	DD *	00016600
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00016610
	LOGICAL LEV, STAGJ, STAGI, ISL	00016620
	DIMENSION NAMEL(13)	00016630
C		00016640
C	GROUND TEMPERATURE (DEG CENTIGRADE) MAP TYPE 24	00016650
C		00016660
	FIM=IM	00016670
	STAGJ=.FALSE.	00016680
	STAGI=.FALSE.	00016690
C		00016700
	DO 110 I=1,NL	00016710
110	NAME(I)=NAMEL(I)	00016720
C		00016730
	DO 150 J=1,JM	00016740
150	ZM(J)=0.0	00016750
C		00016760
	DO 275 I=1,IM	00016770
	DO 275 J=1,JM	00016780
	ACC = GT(J,I) - TICE	00016790
	ZM(J)=ZM(J)+ACC	00016800
275	WORK2(J,I)=ACC*.0001	00016810
C		00016820
	ZMM=0.0	00016830
	WTM=0.0	00016840
	DO 158 J=1,JM	00016850
	WTM=WTM + ABS(DXYP(J))	00016860
	ZM(J)=ZM(J)/FIM	00016870
158	ZMM=ZMM+ZM(J)*ABS(DXYP(J))	00016880
	ZMM=ZMM/WTM	00016890
	SPOL=ZM(1)	00016900
	NPOL=ZM(JM)	00016910
C		00016920
	DATA TICE /273.1/	00016930
	DATA NAMEL/'GROUND TEMPERATURE (DEG CENT)	00016940
	DATA NL/13/	00016950
C		00016960
	RETURN	00016970
	END	00016980

<u>S U B R O U T I N E</u>		
	* <u>MAP25</u>	00016990
//	DD DISP=OLD,DSN=MES727.ABN.COMMON	00017000
//	DD *	00017010
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00017020
	LOGICAL LEV, STAGJ, STAGI, ISL	00017030
	DIMENSION NAMEL(13)	00017040
C		00017050
C	WETNES, MAP TYPE 25	00017060
C		00017070
	FIM=IM	00017080
	IMM2=JM-2	00017090
	JMM1=JM-1	00017100
	STAGJ=.FALSE.	00017110
	STAGI=.FALSE.	00017120
C		00017130
	DO 110 I=1,NL	00017140
110	NAME(1)=NAMEL(I)	00017150
C		00017160
	ZMM=0.0	00017170
	DO 118 J=1,JM	00017180
118	ZM(J)=0.0	00017190
C		00017200
	DO 128 I=1,IM	00017210
	DO 128 J=1,JM	00017220
	ACC=GW(J,I)*10.	00017230
	ZM(J)=ZM(J)+ACC	00017240
128	WORK2(J,I)=ACC	00017250
C		00017260
	WTM=0.0	00017270
	DO 158 J=1,JM	00017280
	WTM=WTM + ABS(DXYP(J))	00017290
	ZM(J)=ZM(J)/FIM	00017300
158	ZMM=ZMM+ZM(J)*ABS(DXYP(J))	00017310
	ZMM=ZMM/WTM	00017320
	SPDL=ZM(1)	00017330
	NPDL=ZM(JM)	00017340
	DATA NAMEL/'GROUND WETNESS (SCALED ZERO TO TEN)	00017350
	DATA NL/13/	00017360
C		00017370
	RETURN	00017380
C		00017390
	END	00017400
		00017410

	<u>S U B R O U T I N E</u>	
	* MAP26	00017420
//	OD DISP=OLD,DSN=MFS727,ARN.COMMON	00017430
//	OD *	00017440
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00017450
	LOGICAL LEV, STAGJ, STAGI, ISL	00017460
	COMMON /EXCOM/CC(46,72,4),CPC1(46,72),CPC3(46,72),	00017470
	* PRCLH(46,72),SR4(46,72)	00017480
	DIMENSION NAME1(13),NAME2(13),NAME3(13)	00017490
C		00017500
C		00017510
	FIM=IM	00017520
	STAGJ=.FALSE.	00017530
	STAGI=.FALSE.	00017540
C		00017550
	K=1	00017560
	IF (SURF.GT.0.5) K=2	00017570
	IF (SURF.EQ.1.0) K=3	00017580
	IF (SURF.GT.1.0) K=4	00017590
	DO 110 I=1,NL	00017595
	NAME(I)=NAME1(I)	00017600
	IF (K.EQ.2) NAME(I)=NAME2(I)	00017610
	IF (K.EQ.4) NAME(I)=NAME4(I)	00017620
110	IF (K.EQ.3) NAME(I)=NAME3(I)	00017625
C		00017630
	DO 150 J=1,JM	00017640
150	ZM(J)=0.0	00017650
C		00017660
	DO 275 I=1,IM	00017670
	DO 275 J=1,JM	00017680
	ACC=CC(J,I,K)	00017690
	IF (ACC.LT.0.0) ACC=0.0	00017700
	ZM(J)=ZM(J)+ACC	00017705
275	WORK2(J,I)=ACC	00017710
C		00017720
	ZMM=0.0	00017730
	WTM=0.0	00017740
	DO 158 J=1,JM	00017750
	WTM=WTM + ABS(OXYP(J))	00017760
	ZM(J)=ZM(J)/FIM	00017770
158	ZMM=ZMM+ZM(J)*ABS(OXYP(J))	00017780
	ZMM=ZMM/WTM	00017790
	SPDL=ZM(1)	00017800
	NPDL=ZM(JM)	00017810
C		00017820
	DATA NAME1/'HIGH CLOUDINESS	00017830
	DATA NAME2/'MIDDLE CLOUDINESS	// 00017840
	DATA NAME3/'LOW CLOUDINESS	// 00017850
	DATA NAME4/'CLOUDINESS	// 00017860
	DATA NL/13/	// 00017865
	RETURN	00017870
C		00017880
	END	00017890
		00017900



	S H R O T I N F	
	* MAP27	00017910
// DO	DISP=OLD,DSN=MES727,AKN,COMMON	00017920
//	DO *	00017930
	COMMON /CONT/ ZM(46),SURF,LEV,ISL,NAME(13)	00017940
	LOGICAL LEV, STAGJ, STAGI, ISL	00017950
	FOI)I VALFNCE (SIGL,SIRF)	00017960
	DIMENSION NAMEL(13)	00017970
C		00017980
	FIM=1M	00017990
C		00018000
	STAGJ=.FALSE.	00018010
	STAGI=.FALSE.	00018020
C		00018030
	DO 110 I=1,NL	00018040
110	NAME(I)=NAMEL(I)	00018050
C		00018060
	DO 220 J=1,JM	00018070
	DO 220 I=1,IM	00018080
220	WORK2(J,I)=PTRDP+SIRF*P(J,I)	00018090
C		00018100
	DO 118 J=1,JM	00018110
118	ZM(J)=0.0	00018120
C		00018130
	ZMM=0.0	00018140
	WTM=0.0	00018150
	DO 430 J=1,JM	00018160
	SUM=0.0	00018170
	CLAT=ARS(DXYP(J))	00018180
	DO 420 I=1,IM	00018190
420	SUM=SUM+WORK2(J,I)	00018200
	ZM(J)=SUM/FIM	00018210
	WTM=WTM+CLAT	00018220
430	ZMM=ZMM+ZM(J)*CLAT	00018230
	ZMM=ZMM/WTM	00018240
	SPOL=ZM(1)	00018250
	NPOL=ZM(JM)	00018260
C		00018270
	DATA NAMEL/'PRESSURE AT SIGMA SURFACE	00018280
	DATA NL/13/	00018290
	RETURN	00018300
C		00018310
	END	00018320
		00018330

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      S U R F I N F
      * MAP2R
// DD DISP=OLD,DSN=MES727.AHN.COMMON
// DD *
COMMON /COUT/ ZM(461,SURF,LEV,ISL,NAMF(13)
LOGICAL LEV, STAGJ, STAGI, ISL
EQUIVALENCE (SIGL,SURF)
COMMON /EXCOM/CC(46,72,41,CPC1(46,72),CPC3(46,72),
* PRCLH(46,72),SR4(46,72)
DIMENSION NAMEL(13)
C
FIM=1M
C
STAGJ=.FALSE.
STAGI=.FALSE.
L1=1
L2=2
SIGL1=SIG(L1)
SIGL2=SIG(L2)
DSIG=1./(SIGL2-SIGL1)
SURFMT=SURF-PTRDP
IF (LEV) SIGX=SIGL
C
DO 110 I=1,NL
110 NAME(I)=NAMEL(I)
C
DO 220 I=1,IM
DO 220 J=1,JM
IF (.NOT.LEVI) SIGX=SURFMT/P(I,J,I)
H1=CPC1(J,I)
H3=CPC3(J,I)
220 WORK2(J,I)=DSIG*((SIGL2-SIGX)*H1 + (SIGX-SIGL1)*H3)
C
DO 118 J=1,JM
118 ZM(J)=0.0
C
ZMM=0.0
WTM=0.0
DO 430 J=1,JM
SUM=0.0
CLAT=ABS(DXYP(J))
DO 420 I=1,IM
420 SUM=SUM+WORK2(I,J,I)
ZM(J)=SUM/FIM
WTM=WTM+CLAT
430 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
SPDL=ZM(1)
NPOL=ZM(JM)
C
DATA NAMEL/'TOTAL CONVECTIVE HEATING (DEG CENT/DAY)
DATA NL/13/
RETURN
C
END

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      S U R F I N F
      * MAP29
// DD DISP=OLD,DSN=MES727.AHN.COMMON
// DD *
COMMON /COUT/ ZM(461,SURF,LEV,ISL,NAME(131
LOGICAL LEV, STAGJ, STAGI, ISL
EQUIVALENCE (SIGL,SURF1
COMMON /EXCOM/CC(46,72,4),CPC1(46,72),CPC3(46,72),
* PRCLH(46,72),SR4(46,72)
DIMENSION NAMEL(131)
C
FIM=FIM
C
STAGJ=.FALSE.
STAGI=.FALSE.
L1=1
L2=2
SIGL1=SIG(L1)
SIGL2=SIG(L2)
DSIG=1./(SIGL2-SIGL1)
SURFMT=SURF-PTROP
IF (LEV) SIGX=SIGL
C
DO 110 I=1,NL
110 NAME(I)=NAMEL(I)
C
DO 220 J=1,JM
DO 220 J=1,JM
IF (.NOT.LEV) SIGX=SURFMT/P(J,I)
H1=0.0
H3=PRCLH(J,I)
220 WORK2(J,I)=DSIG*((SIGL2-SIGX)*H1 + (SIGX-SIGL1)*H3)
C
DO 11A J=1,JM
11A ZM(J)=0.0
C
ZMM=0.0
WTM=0.0
DO 430 J=1,JM
SUM=0.0
CLAT=ABS(DXYP(J))
DO 420 I=1,IM
420 SUM=SUM+WORK2(J,I)
ZM(J)=SUM/FIM
WTM=WTM+CLAT
430 ZMM=ZMM+ZM(J)*CLAT
ZMM=ZMM/WTM
SPDL=ZM(1)
NPDL=ZM(JM)
C
DATA NAMEL/'LATENT HEATING IN LAYER (DEG CENT/DAY)
DATA NL/13/
RETURN
C
END

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	<u>S U R F A C E</u>	
	* MAP30	00019440
// DO	DISP=DL0,DSN=MES727,ARN,COMMON	00019450
// DO	*	00019460
	COMMON /COUT/ ZM(46),SURF,LEV,ISL,NAME(13)	00019470
	LOGICAL LEV, STAGJ, STAGI, ISL	00019480
	COMMON /EXCOM/CC(46,72,4),CPC1(46,72),CPC3(46,72),	00019490
	* PRCLH(46,72),SR4(46,72)	00019500
	DIMENSION NAMEL(13)	00019510
C		00019520
C		00019530
	FIM=JM	00019540
	STAGJ=.FALSE.	00019550
	STAGI=.FALSE.	00019560
C		00019570
	DO 110 J=1,NL	00019580
110	NAME(J)=NAMEL(J)	00019590
C		00019600
	DO 150 J=1,JM	00019610
150	ZM(J)=0.0	00019620
C		00019630
	DO 275 J=1,IM	00019640
	DO 275 J=1,JM	00019650
	ACC=.01*SR4(J,J)	00019660
	ZM(J)=ZM(J)+ACC	00019670
275	WORK2(J,J)=ACC	00019680
C		00019690
	ZMM=0.0	00019700
	WTM=0.0	00019710
	DO 158 J=1,JM	00019720
	WTM=WTM + ABS(OXYP(J))	00019730
	ZM(J)=ZM(J)/FIM	00019740
158	ZMM=ZMM+ZM(J)*ABS(OXYP(J))	00019750
	ZMM=ZMM/WTM	00019760
	SPNL=ZM(1)	00019770
	NPNL=ZM(JM)	00019780
C		00019790
	DATA NAMEL/'SURFACE LONG-WAVE COOLING (100 CAL/CM**2/DAY)	00019800
	DATA NL/13/	// 00019810
	RETURN	00019820
C		00019830
	END	00019840
		00019850

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      S U R F A C E
      * MAP31
// DO DISP=NL0,DSN=MES727,ABN.COMMON
// DO *
      COMMON /COUT/ ZM(46),SURF,LFV,ISL,NAME(13)
      LOGICAL LFV, STAGJ, STAG1, ISL
      COMMON /EXCOM/CL(46,72,4),CPC1(46,72),CPC3(46,72),
      * PRCLH(46,72),SR4(46,72)
      DIMENSION NAMEL(13)
C
C
      FIM=1M
      STAGJ=.FALSE.
      STAG1=.FALSE.
C
C
C
      CALL MAP 22
      DO 275 I=1,1M
      DO 275 J=1,JM
275 WORK1(J,I)=WORK2(J,I)
      CALL MAP 30
      DO 280 I=1,1M
      DO 280 J=1,JM
280 WORK1(J,I)=WORK1(J,I)-WORK2(J,I)
      CALL MAP 15
      DO 285 I=1,1M
      DO 285 J=1,JM
285 WORK1(J,I)=WORK1(J,I)-0.1*WORK2(J,I)
      CALL MAP 14
      DO 290 I=1,1M
      DO 290 J=1,JM
290 WORK2(J,I)=WORK1(J,I)-0.580*WORK2(J,I)
      DO 150 J=1,JM
150 ZM(J)=0.0
      DO 300 I=1,1M
      DO 300 J=1,JM
300 ZM(J)=ZM(J)+WORK2(J,I)
C
      ZMM=0.0
      WTM=0.0
      DO 158 J=1,JM
      WTM=WTM + ABS(DXYP(J))
      ZM(J)=ZM(J)/FIM
158 ZMM=ZMM+ZM(J)*ABS(DXYP(J))
      ZMM=ZMM/WTM
      SPOL=ZM(1)
      NPOL=ZM(JM)
      DO 110 I=1,N(
110 NAME(1)=NAMEL(1)
C
      DATA NAMEL/'SURFACE HEAT BALANCE (100 CAL/CM**2/DAY)
      DATA NL/13/
      RETURN
C
      ENH

```

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00019860
00019870
00019880
00019890
00019900
00019910
00019920
00019930
00019940
00019950
00019960
00019970
00019980
00019990
00020000
00020010
00020020
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00020190
00020200
00020210
00020220
00020230
00020240
00020250
00020260
00020270
00020280
00020290
00020300
00020310
00020320
00020330
00020340
00020350
00020360
// 00020370
00020380
00020390
00020400
00020410

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      *          S U B R O U T I N E
      *          CNMP3
      *          00020420
/*          *          00020430
// 00 OISP=OLO,DSN=MES727.ABN.COMMON 00020440
//          00          *          00020450
      EQUIVALENCE (KKK,XXX) 00020460
      LOGICAL ICE, LAND, PCFAN, SNOW, KEY 00020470
      COMMON /EXCOM/CC(46,72,4),CPC1(46,72),CPC3(46,72), 00020480
      *          PRCLH(46,72),SR4(46,72) 00020490
C          00020500
      TRANS(X)=1./(1.+1.75*X**.416) 00020510
      TRSW(X)=1.-.271*X**.303 00020520
C          00020530
      JMM1=JM-1 00020540
      IMM2=IM-2 00020550
      JMM2=JM-2 00020560
      IM=IM/2+1 00020570
      FIM=IM 00020580
      SIG1=SIG(1) 00020590
      SIG3=SIG(2) 00020600
      DSIG=SIG3-SIG1 00020610
C          00020620
      GWM=30. 00020630
      DTC3=FLOAT(NC3)*NT 00020640
      RCNV=DTC3/TCNV 00020650
      CLH=580./24 00020660
      PLOK=1000.**KAPA 00020670
      CTI=.005 00020680
      CTID=.64E4*CTI 00020690
      HICE=300. 00020700
      TICE=273.1 00020710
C          00020720
      PM=PSL-PTRNP 00020730
      CNE=GRAV*100./(10.5*PM*1000.*0.24) 00020740
      CNE1=COF*DTC3/(24.*3600.) 00020750
      SCALEF=CNE*100. 00020760
      TSPD=DAY/DTC3 00020770
      SCALEP=TSPD*.5*(10./GRAV)*100. 00020780
      CNRAD=180./PI 00020790
      CNRX=CONRAD*.01 00020800
      FSEDY=SEFDY 00020810
      SNOWN=(60.-15.*COS(.9863*(FSEDY-24.668)/CONRAD))/CONRAD 00020820
      SNOWS=-60./CONRAD 00020830
C          00020840
C          00020850
C          00020860
      SURFACE WIND MAGNITUDE 00020870
      DO 10 I=1,IM 00020880
      DO 10 J=2,JM 00020890
      US=2.*(SIG3*U(J,I,2)-SIG1*U(J,I,1))*0.7 00020900
      VS=2.*(SIG3*V(J,I,2)-SIG1*V(J,I,1))*0.7 00020910
      FD(J,I)=US*US + VS*VS 00020920
      WMAG1=SQRT(.5*(FD(2,1)+FD(2,IM))) 00020930
      WMAGJM=SQRT(.5*(FD(JM,1)+FD(JM,IM))) 00020940

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C		00020950
C	RADIATION CONSTANTS	00020960
C		00020970
	SO=2880./RSNIST	00020980
	ALC1=.7	00020990
	ALC2=.6	00021000
	ALC3=.6	00021010
	STRN=1.171E-7	00021020
	EFVC1=65.3	00021030
	EFVC2=65.3	00021040
	EFVC3=7.6	00021050
	CPART=.5*1.3071E7	00021060
	ROT = TINFDAY/ROTPFR*2.0*PI	00021070
C		00021080
C	HEATING LOOP	00021090
C		00021100
	DO 370 I=1,IM	00021110
	IM1=MOD(I+IMM2,IM)+1	00021120
	IP1=MOD(I,IM)+1	00021130
	FIM1=I-1	00021140
	HACOS=COSD*CONS(ROT+FIM1*DLON)	00021150
	DO 360 J=1,JM	00021160
	COSZ=SINL(J)*SIND+COSL(J)*HACOS	00021170
C		00021180
C	SURFACE CONDITION	00021190
C		00021200
	TG00=TDPNG(J,I)	00021210
	OCEAN=TG00.GT.1.	00021220
	ICE=TG00.LE.-9.9F5	00021230
	LAND=.NOT.(ICE.OR.OCEAN)	00021240
	SNOW=LAND.AND.(LAT(J).GE.SNOWN.OR.LAT(J).LE.SNOWS)	00021250
	LAND=LAND.AND..NOT.SNOW	00021260
	IF (.NOT.OCEAN) ZZZ=VPHI4(J,I)/GRAV	00021270
C	DRAW COEFFICIENT	00021280
	IF (J.EQ.1) WMAG=WMAG1	00021290
	IF (J.EQ.JM) WMAG=WMAGJM	00021300
	IF (J.NE.1.AND.J.NE.JM) WMAG=SQRT(.25*(FD(J,I)+FD(J+1,I)	00021310
	X +FD(J,IM1)+FD(J+1,IM1)))	00021320
	CD = .002	00021330
	IF (.NOT.OCEAN) CD=CD+0.006*ZZZ/5000.	00021340
	IF (OCEAN) CD = AMIN1((1.0+.07*WMAG)*.001,.0025)	00021350
	CS = CD*100.	00021360
	CS4 = .24*CS*24.*3600.	00021370
	FK1 = CD*(10.*GRAV)/(DSIG*PM)	00021380

C		00021390
C	PRESSURES	00021400
C		00021410
	SP=P(J,1)	00021420
	CNLMR=PM/SP	00021430
	P4=SP+PTRNP	00021440
	P4K=P4**KAPA	00021450
	PL1=SIG1*SP+PTRNP	00021460
	PL2=.5*SP+PTRNP	00021470
	PL3=SIG3*SP+PTRNP	00021480
	PL1K=PL1**KAPA	00021490
	PL3K=PL3**KAPA	00021500
	PL2K=PL2**KAPA	00021510
	PTRK=PTRNP**KAPA	00021520
	DPLK=PL3K-PL1K	00021530
C		00021540
C	TEMPERATURES AND TEST FOR DRY-ADIABATIC INSTABILITY	00021550
C		00021560
	T1=T(J,1,1)	00021570
	T3=T(J,1,2)	00021580
	THL1=T1/PL1K	00021590
	THL3=T3/PL3K	00021600
	IF (THL1 .GT. THL3) GO TO 310	00021610
	XX1=(T1+T3)/(PL1K+PL3K)	00021620
	T1=XX1*PL1K	00021630
	T3=XX1*PL3K	00021640
	THL1=T1/PL1K	00021650
	THL3=T3/PL3K	00021660
C		00021670
C	MOISTURE VARIABLES	00021680
C		00021690
310	FS1=10.0**((8.4051-2353.0/T1))	00021700
	FS3=10.0**((8.4051-2353.0/T3))	00021710
	P1CB=.1*PL1	00021720
	P3CB=.1*PL3	00021730
	P4CB=.1*P4	00021740
	QS1=.622*ES1/(P1CB-FS1)	00021750
	QS3=.622*ES3/(P3CB-FS3)	00021760
	GAM1=CLH*QS1*5418./T1**2	00021770
	GAM3=CLH*QS3*5418./T3**2	00021780
	Q3R=Q3(J,1)	00021790
	RH3=Q3R/QS3	00021800
C		00021810
C	TEMPERATURE EXTRAPOLATION AND INTERPOLATION FOR RADIATION	00021820
C		00021830
	ATEM=(THL3-THL1)/DPLK	00021840
	BTEM=(THL1*PL3K-THL3*PL1K)/DPLK	00021850
	TTRDP=(ATEM*PTRK+BTEM)*PTRK	00021860
	T2=(ATEM*PL2K+BTEM)*PL2K	00021870



C		00021880
C	GROUND TEMPERATURE AND WETNESS	00021890
C	TG=TG00	00021900
	WET=1.0	00021910
	IF (.NOT.OCEAN) TG=GT(J,1)	00021920
	IF (LAND) WET=GW(J,1)	00021930
C		00021940
C	LARGE SCALE PRECIPITATION	00021950
C		00021960
	PREC=0.	00021970
	IF (Q3R.LE.QS3) GO TO 1060	00021980
	PREC=(Q3R-QS3)/(1.+GAM3)	00021990
	T3=T3+CLH*PREC	00022000
	THL3=T3/PL3K	00022010
	Q3R=Q3R-PREC	00022020
C		00022030
C	CONVECTION	00022040
C		00022050
	1060 TETA1=THL1*P10K	00022060
	TETA3=THL3*P10K	00022070
	SS3 = TETA3*P4K/P10K	00022080
	SS2 = SS3 + 0.5*(TETA1-TETA3)*PL2K/P10K	00022090
	SS1 = SS2 + 0.5*(TETA1-TETA3)*PL2K/P10K	00022100
	HH3 = SS3 + CLH*Q3R	00022110
	HH3S = SS3 + CLH*QS3	00022120
	HH1S = SS1 + CLH*QS1	00022130
C		00022140
C	MIDDLE LEVEL CONVECTION	00022150
C		00022160
	C1 = 0.	00022170
	C3 = 0.	00022180
	EX = HH3 - HH1S	00022190
	IF (EX.LE.0.) GO TO 1065	00022200
	C1 = RCNV*EX/(2.+GAM1)	00022210
	C3 = C1*(1.+GAM1)*(SS2-SS3)/(EX+(1.+GAM1)*(SS1-SS2))	00022220
C		00022230
C	PREPARATION FOR AIR-EARTH INTERACTION	00022240
C		00022250
	1065 ZL3 = 2000.	00022260
	WINDF=2.0+WMAG	00022270
	DRAW=CD*WINDF	00022280
	EDV=ED/ZL3*WMAG/10.	00022290
		00022300

C		00022310
C	DETERMINATION OF SURFACE TEMPERATURE	00022320
C		00022330
C		00022340
	1070 RH4=2.*WET*RH3/(WET+RH3)	00022350
	EG=10.*(8.4051-2353./TG)	00022360
	EG= AMIN1(EG,P4CB/1.662)	00022370
	QG=.622*EG/(P4CB-FG)	00022380
	QQG=5418.*QG/TG**2	00022390
	HHG=TG+CLH*QG*WET	00022400
	EDR=EDV/(EDV+DRAW)	00022410
	HH4=EDR*HH3+(1.-EDR)*HHG	00022420
	GAMG=CLH*QQG	00022430
	T4=(HH4-RH4*(CLH*QG-GAMG*TG))/(1.+RH4*GAMG)	00022440
	IF (T4*P10K/P4K.GT.TETA3) T4=TETA3*P4K/P10K	00022450
	Q4=RH4*(QG+QQG*(T4-TG))	00022460
	HH4=T4+CLH*Q4	00022470
C		00022480
C	PENETRATING AND LOW-LEVEL CONVECTION	00022490
C		00022500
	PC1=0.	00022510
	PC3=0.	00022520
	EX=0.	00022530
	IF (HH4 .LE. HH3S) GO TO 1077	00022540
	IF (HH3 .GT. HH1S) GO TO 1077	00022550
	EX = HH4-HH3S	00022560
	HH4P = HH4	00022570
	HH4 = HH3S	00022580
	IF (HH4P .LT. HH1S) GO TO 1076	00022590
	ETA = 1.	00022600
	TEMP1 = ETA*((HH3S-HH1S)/(1.+GAM1))+SS1-SS2)	00022610
	TEMP2 = ETA*(SS2-SS3) + (SS3-T4)	00022620
	TEMP = EDR*TEMP1+(1.+GAM3)*TEMP2	00022630
	IF (TEMP .LT. .001) TEMP=.001	00022640
	CONVP = RCNV*EX/TEMP	00022650
	PC1 = CONVP*TEMP1	00022660
	PC3 = CONVP * TEMP2	00022670
C		00022680
	1076 T4=T4-EX/(1.+RH4*GAMG)	00022690
	Q4=(HH4-T4)/CLH	00022700
C		00022710
	1077 R04=P4CB/(RGAS*T4)	00022720
	CSE'=CS4*R04*WINOF	00022730
	CEVA=CS*R04*WINOF	00022740

C		00022750
C	CLOUDINESS	00022760
C		00022770
	ICLOUD=1	00022780
	CL=0.	00022790
	CL1=0.	00022800
	CL2=0.	00022810
	CL3=0.	00022820
	CLT=0.	00022830
	CL=AMIN1(-1.3+2.6*RH3,1.)	00022840
	IF (CL.GT.0..OR.PC1.GT.0.) CL1=CL	00022850
	IE (PREC.GT.0..AND.CL1.EQ.0.) CL2=1.	00022860
	IE (EX.GT.0..AND.PC1.EQ.0.) CL3=CL	00022870
C	=====	00022880
C		00022890
C		00022900
C		00022910
C		00022920
C		00022930
C		00022940
C		00022950
C		00022960
C		00022970
C		00022980
C		00022990
C		00023000
C		00023010
C		00023020
C		00023030
C	=====	00023040
	CL=AMAX1(CL1,CL2,CL3)	00023050
	IF (CL .GE. 1.) ICLOUD=3	00023060
	IF (CL .LT. 1. .AND. CL .GT. 0.) ICLOUD=2	00023070
C		00023080
C	ICLOUD=1 CLEAR, ICLOUD=2 PARTLY CLOUDY, ICLOUD=3 OVERCAST	00023090
C	LONG WAVE RADIATION	00023100
C		00023110
1080	Q3RB=AMAX1(Q3R,1.E-5)	00023120
	VAK=2.+ALOG(1.7188E-6/Q3RB)/ALOG(120./PL3)	00023130
	TEM1=.00102*PL3**2*Q3RB/VAK	00023140
	TEM2=TEM1*(P4/PL3)**VAK	00023150
	EFV3=TEM2-TEM1	00023160
	EEV2=TEM2-TEM1*(PL2/PL3)**VAK	00023170
	FFV1=TEM2-TEM1*(PL1/PL3)**VAK	00023180
	EFVT=TEM2-TEM1*(PTRDP/PL3)**VAK	00023190
	EFV0=TEM2-TEM1*(120./PL3)**VAK+2.526E-5	00023200
	BLT=STR0*TTROP**4	00023210
	BL1=STR0*T1**4	00023220
	BL2=STR0*T2**4	00023230
	BL3=STR0*T3**4	00023240
	BL4=STR0*T6**4	00023250

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C      LONG WAVE RADIATION
      ROC=0.
      R2C=0.
      R4C=0.
      URT=BLT*TRANS(EFV0-EFVT)
      UR2=BL2*TRANS(EFV0-EFV2)
      GO TO (1090,1090,2000), ICLNUD
1090  R00=0.82*(URT+(BL4-BLT)*(1.+TRANS(EFVT))/2.)
      R20=0.736*(UR2+(BL4-BL2)*(1.+TRANS(EFV2))/2.)
      R40=BL4*(0.6*SQR(TTRANS(EFV0))-0.1)
      IF (ICLNUD .EQ. 1) GO TO 2015
2000  IF (CL2 .LE. 0.) GO TO 2004
      CLT=CL2
      ROC=0.82*(URT+(BL2-BLT)*(1.+TRANS(EFVT-EFV2))/2.)*CLT
      R2C=0.736*UR2*CLT
      R2C=.5*R2C
      GO TO 2006
2004  IF (CL3 .LE. 0.) GO TO 2006
      CLT=CL3
      ROC=0.82*(URT+(BL3-BLT)*(1.+TRANS(EFVT-EFV3))/2.)*CLT
      R2C=0.736*(UR2+(BL3-BL2)*(1.+TRANS(EFV2-EFV3))/2.)*CLT
2006  IF (CL1 .LE. 0.) GO TO 2010
      CLM=AMAX1(CLT-CL1,0.)
C      IN PRESENT VERSION, CLM AND THIS TEM ARE ALWAYS ZERO
      TEM=0.
      IF (CLT .GT. 0.001) TEM=CLM/CLT
      ROC=0.82*(URT+(BL1-BLT)*(1.+TRANS(EFVT-EFV1))/2.)*CL1+ROC*TEM
      R2C=R2C*TEM
2010  R4C=0.85*(.25+.75*TRANS(EFV3))*(BL4-BL3)*CL
2015  R0=ROC+(1.-CL)*R00
      R2=R2C+(1.-CL)*R20
      R4=R4C+(1.-CL)*R40
      OIRAD=4.*STRN*TG**3
C
C      SURFACE ALBEDO
C
      IF (COSZ .LE. .01) GO TO 340
      SCOSZ=S0*COSZ
      ALS=.07
      IF (OCEAN) GO TO 335
      ALS=.14
      IF (LAT(J) .LT. SNOWN) GO TO 327
      CLAT=(LAT(J)-SNOWN)*CONRAD
      GO TO 330
327  IF (LAT(J) .GT. SNOWS) GO TO 328
      CLAT=(SNOWS-LAT(J))*CONRAD
      ALS=.45*(1.+(CLAT-10.)**2)/((CLAT-30.)**2+(CLAT-10.)**2)
      GO TO 335
328  IF (LAND) GO TO 335
      CLAT=0.0
330  ALS=.4*(1.+(CLAT-5.)**2)/((CLAT-45.)**2+(CLAT-5.)**2)

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C		00023770
C	SOLAR RADIATION	00023780
C		00023790
335	ALAO=AMIN1(1.,.085-.247*ALOG10(COSZ/COLMR))	00023800
	SA=.349*SCOSZ	00023810
	SS=SCOSZ-SA	00023820
	ASOT=SA*TRSW((EFV0-EFV1)/COSZ)	00023830
	AS2T=SA*TRSW((EFV0-EFV2)/COSZ)	00023840
	FS2C=0.	00023850
	FS4C=0.	00023860
	S4C=0.	00023870
	GO TO (336,336,337), ICLDUD	00023880
C	CLEAR	00023890
336	FS20=AS2T	00023900
	FS40=SA*TRSW(EFV0/COSZ)	00023910
	S40=(1.-ALS)*(FS40+(1.-ALAO)/(1.-ALAO*ALS)*SS)	00023920
	IF (ICLDUD .EQ. 1) GO TO 341	00023930
C	LARGE SCALE CLOUD	00023940
337	IF (CL2 .LE. 0.) GO TO 338	00023950
	CLT=CL2	00023960
	FS2C=AS2T*CLT	00023970
	TFMS=SA*(1.-ALC2)*TRSW((EFV0-EFV2)/COSZ+1.66*(EFVC2+EFV3))	00023980
	FS4C=(TFMS+ALC2*AS2T)*CLT	00023990
	ALAC=ALC2+ALAO-ALC2*ALAO	00024000
	S4C=(1.-ALS)*(TFMS/(1.-ALC2*ALS)+(1.-ALAC)/(1.-ALAC*ALS)*SS)*CLT	00024010
	GO TO 339	00024020
C	LOW LEVEL CLOUD	00024030
338	IF (CL3 .LE. 0.) GO TO 339	00024040
	CLT=CL3	00024050
	FS2C=AS2T*CLT	00024060
	TFMU=(EFV0-EFV3)/COSZ	00024070
	TFMS=SA*(1.-ALC3)*TRSW(TFMU+1.66*(EFVC3+EFV3))	00024080
	FS4C=(TFMS+ALC3*SA*TRSW(TFMU))*CLT	00024090
	ALAC=ALC3+ALAO-ALC3*ALAO	00024100
	S4C=(1.-ALS)*(TFMS/(1.-ALC3*ALS)+(1.-ALAC)/(1.-ALAC*ALS)*SS)*CLT	00024110
C	THICK CLOUD	00024120
339	IF (CL1 .LE. 0.) GO TO 341	00024130
	CLM=AMAX1(CLT-CL1,0.)	00024140
C	IN PRESENT VERSION, CLM AND THIS TFM ARE ALWAYS ZERO	00024150
	TFM=0.	00024160
	IF (CLT .GT. 0.) TFM=CLM/CLT	00024170
	TFMU=(EFV0-EFV1)/COSZ	00024180
	TFMB=ALC1*TRSW(TFMU)*SA*CL1	00024190
	FS2C=SA*(1.-ALC1)*TRSW(TFMU+1.66*EFVC1)*CL1+TFMB+FS2C*TFM	00024200
	TFMS=SA*(1.-ALC1)*TRSW(TFMU+1.66*(EFVC1+EFV3))	00024210
	FS4C=TFMS*CL1+TFMB+FS4C*TFM	00024220
	ALAC=ALC1+ALAO-ALC1*ALAO	00024230
	S4C=(1.-ALS)*(TFMS/(1.-ALC1*ALS)	00024240
	X + (1.-ALAC)/(1.-ALAC*ALS)*SS)*CL1+S4C*TFM	00024250

C	MEAN CONDITION	00024260
341	FS2=FS2C+(1.-CL)*FS20	00024270
	FS4=FS4C+(1.-CL)*FS40	00024280
	S4=S4C+(1.-CL)*S40	00024290
	AS1=AS0T-FS2	00024300
	AS3=FS2-FS4	00024310
	GO TO 345	00024320
340	S4=0.0	00024330
	AS3=0.0	00024340
	AS1=0.0	00024350

C		00024360
C	COMPUTATION OF GROUND TEMPERATURE	00024370
C		00024380
	345 TGR=TG	00024390
	IF (NCFAN) GO TO 347	00024400
	BRAD=S4-R4	00024410
	TFM=0.	00024420
	IF (ICE.AND.ZZZ.LT.0.1) TFM=CTID/HICE	00024430
	A1=CSEN*(T4+CLH*(Q4+WET*(DQG*TG-QG)))	00024440
	A2=BRAD+4.*RL4+TFM*TICF	00024450
	B1=CSEN*(1.+CLH*DQG*WET)	00024460
	B2=DIRAD+TEM	00024470
	TGR=(A1+A2)/(B1+B2)	00024480
	IF (LAND.OR.TGR.LT.TICE) GO TO 346	00024490
	TGR=TICF	00024500
	346 DR4=DIRAD*(TGR-TG)	00024510
	R4=R4+DR4	00024520
	R2=R2+.8*(1.-CL)*TRANS(FFV2)*DR4	00024530
	RO=RO+.8*(1.-CL)*TRANS(FFVT)*DR4	00024540
	347 CONTINUE	00024550
C		00024560
C	SENSIBLE HEAT (LY/DAY) AND EVAPORATION (GM/CM**2/SEC)	00024570
C		00024580
	E4=CFVA*(WET*(QG+DQG*(TGR-TG))-Q4)	00024590
	F4=CSFN*(TGR-T4)	00024600
	FK=RO4*FK1*WINDF	00024610
C		00024620
C	TOTAL HEATING AND MOISTURE BUDGET	00024630
C		00024640
	QN=(C1+C3+PC1+PC3)/CLH+PREC-2.*E4*DTC3*GRAV/(SP*10.)	00024650
	IF (.NOT.LAND) GO TO 350	00024660
	RUNOFF=0.	00024670
	IF (QN.GT.0. .AND. WET.LT.1.) RUNOFF=.5*WET	00024680
	IF (QN.GT.0. .AND. WET.GE.1.) RUNOFF=1.	00024690
	WET = GW(J,I)+(1.-RUNOFF)*QN*.5*SP/GRAV/GWM	00024700
	IF (WET.GT.1.) WET = 1.	00024710
	IF (WET.LT.0.) WET = 0.	00024720
	350 CONTINUE	00024730
C		00024740
	351 H1=(AS1+R2-R0)*COE1*COLMR+C1+PC1	00024750
	H3=(AS3+R4-R2+F4)*COE1*COLMR+C3+PC3+PREC*CLH	00024760
	H(J,I,1)=0.5*(H1+H3)	00024770
	TFMP=0.5*(H1-H3)	00024780
C		00024790
C	SURFACE FRICTION	00024800
C		00024810
	352 CONTINUE	00024820
	355 CONTINUE	00024830
C		00024840
	358 CONTINUE	00024850

C		00024860
C	PACK FOR OUTPUT	00024870
C		00024880
	WW=0.0	00024890
	CC(J,1,1)=CL1	00024900
	CC(J,1,2)=CL2	00024910
	CC(J,1,3)=CL3	00024920
	CC(J,1,4)=CL	00024925
	CPC1(J,1)=(C1+PC1)*DAY/DTC3	00024930
	CPC3(J,1)=(C3+PC3)*DAY/DTC3	00024940
	CPC1(J,1)=C1+PC1	00024950
	CPC3(J,1)=C3+PC3	00024960
	PRCLH(J,1)=PRFC*CLH*DAY/DTC3	00024970
	SR4(J,1)=R4	00024980
	SCALE=SCALEH*CONLMR	00024990
	KKK=IPK(IFIX(AS1*SCALE),IFIX(AS3*SCALE))	00025000
	TT(J,1,1)=XXX	00025010
	KKK=IPK(IFIX((R2-R0)*SCALE),IFIX((R4-R2)*SCALE))	00025020
	VT(J,1,2)=XXX	00025030
	KKK=IPK(IFIX(F4),IFIX(E4*100.*3600.*24.))	00025040
	TT(J,1,2)=XXX	00025050
	KKK=IPK(IFIX(T4*10.),IFIX(PRFC*SCALEP*SP))	00025060
	Q3T(J,1)=XXX	00025070
	KKK=IPK(IFIX(EX*10.),IFIX((C1+C3+PC1+PC3)*SP*SCALEP/CLH))	00025080
	UT(J,1,2)=XXX	00025090
	KKK=IPK(IFIX(H1*100.*DAY/DTC3),IFIX(H3*100.*DAY/DTC3))	00025100
	PT(J,1)=XXX	00025110
	KKK=IPK(IFIX(S4/10.),IFIX(WW*100.))	00025120
	SD(J,1)=XXX	00025130
360	CONTINUE	00025140
370	CONTINUE	00025150
375	CONTINUE	00025160
377	CONTINUE	00025170
380	CONTINUE	00025180
390	CONTINUE	00025190
400	RETURN	00025200
	END	00025210



## VIII. FORTRAN DICTIONARY

### PURPOSE

In order to permit the efficient reading of the FORTRAN program and map routine listings, all of the FORTRAN variables used in the code are collected below. For each FORTRAN term a brief identification or meaning is given, together with the term's units (if any) and the location of its first appearance or definition in the program. The locations are not given for certain symbols of widespread use, and those FORTRAN symbols used only in the output map routines of Chapter VII, Section B, are not listed. Conventional FORTRAN notation has been used, with the equivalence in terms of the physical symbols of the model also given where appropriate.

TERM LIST

FORTRAN Symbol	Meaning	Units	Program Location
A	$AX \times 10^5$ , horizontal momentum diffusion coefficient (zero in present version)	$m^2 sec^{-1}$	13570 INPUT
ALAC	$\alpha_{ac} = \alpha_{c_1} + \alpha_o - \alpha_{c_1} \alpha_o$ , albedo of cloudy atmosphere for Rayleigh scattering	--	10650 COMP 3
ALAO	$\alpha_o$ , albedo of clear sky for Rayleigh scattering	--	10450 COMP 3
ALC1	$\alpha_{c_1}$ , albedo of type 1 (penetrating convective) cloud, = 0.7	--	7610 COMP 3
ALC2	$\alpha_{c_2}$ , albedo of type 2 (middle-level overcast) cloud, = 0.6	--	7620 COMP 3
ALC3	$\alpha_{c_3}$ , albedo of type 3 (low-level convective) cloud, = 0.6	--	7630 COMP 3
ALP	$(m/n - 1)/8$ , longitudinal smoothing parameter	--	6920 AVRX
ALPH(8)	identification parameter (not used)	--	--
ALPHA	(1) $FXCO*(P(J,I)+(P(J-1,I))*(FD(J,I)+FD(J-1,I)))$ Coriolis force parameter	$m^2 mb$	5160 COMP 2
	(2) $ALP/FNM$ , longitudinal smoothing weighting factor	--	6950 AVRX
ALS	$\alpha_s$ , surface albedo (0.07 for ocean, 0.14 for bare land, a defined function of latitude for ice and snow)	--	10290-10410 COMP 3
AMONTH(3)	name of month	--	--
APHEL	aphelion, 1 July (= 183.0)	day	13110 INPUT

FORTRAN Symbol	Meaning	Units	Program Location
ASOT	$S_T^A$ , flux at tropopause of solar radiation subject to absorption	$ly\ day^{-1}$	10480 COMP 3
AS1	$A_1$ , insolation absorbed by upper layer (= 0 if $\cos \zeta \leq 0.01$ )	$ly\ day^{-1}$	10950 COMP 3
AS2T	$(S_2^A)'$ , flux at level 2 of solar radiation subject to absorption (= FS20)	$ly\ day^{-1}$	10490 COMP 3
AS3	$A_3$ , insolation absorbed by lower layer (= 0 if $\cos \zeta \leq 0.01$ )	$ly\ day^{-1}$	10960 COMP 3
ATEM	$(\theta_3 - \theta_1)/(p_3^K - p_1^K)$ , temperature interpolation parameter	$deg(mb)^{-2\kappa}$	8490 COMP 3
AX	horizontal momentum diffusion coefficient (= 0 in present version)	$m^2\ sec^{-1}$	13380 INPUT
AXU(J)	$A(DXU(J)/300\ km)^{4/3}$ , zonal momentum diffusion coefficient (not used)	$m^2\ sec^{-1}$	14800 MAGFAC
AXV(J)	$A(DXP(J)/300\ km)^{4/3}$ , zonal momentum diffusion coefficient (not used)	$m^2\ sec^{-1}$	14810 MAGFAC
AYU(J)	$A(DYU(J)/300\ km)^{4/3}$ , meridional momentum diffusion coefficient (not used)	$m^2\ sec^{-1}$	14820 MAGFAC
AYV(J)	$A(DYP(J)/300\ km)^{4/3}$ , meridional momentum diffusion coefficient (not used)	$m^2\ sec^{-1}$	14830 MAGFAC
A1	$C_T \left\{ T_4 + \frac{L}{c_p} \left( q_4 + WET \left[ T_g \frac{dq_s(T_g)}{dT} - q_s(T_g) \right] \right) \right\}$ ground temperature parameter	$ly\ day^{-1}$	11090 COMP 3

FORTRAN Symbol	Meaning	Units	Program Location
A2	$S_4 - \tilde{R}_4 + 4\sigma T_g^4 + \tilde{B}T_o$ , ground temperature parameter	$ly\ day^{-1}$	11100 COMP 3
BCOMN (67040)	common block (see Chapter VII, Subsection A.3)	(various)	0140 COMMON
BIT	control parameter (not used)	--	--
BLANK	logical variable control	--	--
BLT	$\sigma T_T^4$ , long-wave radiation parameter at tropopause	$ly\ day^{-1}$	9860 COMP 3
BL1	$\sigma T_1^4$ , long-wave radiation parameter at level 1	$ly\ day^{-1}$	9870 COMP 3
BL2	$\sigma T_2^4$ , long-wave radiation parameter at level 2	$ly\ day^{-1}$	9880 COMP 3
BL3	$\sigma T_3^4$ , long-wave radiation parameter at level 3	$ly\ day^{-1}$	9890 COMP 3
BL4	$\sigma T_g^4$ , long-wave radiation parameter at ground level	$ly\ day^{-1}$	9900 COMP 3
BRAD	$S_4 - \tilde{R}_4$ , ground radiation balance (uncorrected for $T_g$ )	$ly\ day^{-1}$	11060 COMP 3
BTEM	$(\theta_1 p_3^K - \theta_3 p_1^K)/(p_3^K - p_1^K)$ , temperature interpolation parameter	$deg(mb)^{-K}$	8500 COMP 3
B1	$C_T(1 + \gamma_g\ WET)$ , ground temperature parameter	$ly\ day^{-1} deg^{-1}$	11110 COMP 3

FORTRAN Symbol	Meaning	Units	Program Location
B2	$4\sigma T_g^3 + \tilde{B}$ , ground temperature parameter ( $\tilde{B} = 0$ unless over ice)	$\text{ly day}^{-1} \text{deg}^{-1}$	11120 COMP 3
C(K)	equivalence array (see Chapter VII, Subsection A.3)	(various)	0430 COMMON
CD	$C_D$ , surface drag coefficient	--	7970-7980 COMP 3
CENTIG	identification for sea-surface temperature	--	--
CEVA	$100 C_D \rho_4 ( \vec{V}_g ^2 + G)$ , surface evaporation parameter	$\text{g cm}^{-2} \text{sec}^{-1}$	9390 COMP 3
CHECK	data control parameter (not used)	--	--
CL	$\max(\text{CL1}, \text{CL2}, \text{CL3})$ , fraction of sky covered by cloud	--	9700 COMP 3
CLAT	degrees poleward of snowline, used in surface albedo calculation $(\varphi_j - \text{SNOWN}, \text{SNOWS} - \varphi_j) * \text{CONRAD}$ for (northern, southern) hemisphere	$\text{deg lat}$	10330, 10360 COMP 3
CLH	$L/c_p$ , latent heat to specific heat ratio (= 580/.24)	deg	7300 COMP 3
CLKSW	input identification	--	--
CLM	$\max(\text{CLT} - \text{CL1}, 0)$ , cloud parameter (not used)	--	10130 COMP 3
CLT	0, CL2 or CL3, cloud parameter (not used)	--	10030 COMP 3

FORTRAN Symbol	Meaning	Units	Program Location
CL1	min(-1.3 + 2.6RH3, 1), fraction of sky covered by type 1 (penetrative convective) cloud	--	9500 COMP 3
CL2	fraction of sky covered by type 2 (large-scale condensation) cloud (either 0 or 1)	--	9510 COMP 3
CL3	min(-1.3 + 2.6RH3, 1), fraction of sky covered by type 3 (low-level convective) cloud	--	9520 COMP 3
CNRX	0.01*C0NRAD, unit conversion factor (not used)	deg/radian	7440 COMP 3
CNST	GRAV*30.48*HCST, unit conversion factor for surface elevation	--	16200, 16270 INIT 2
C0E	200g/c <sub>p</sub> (p <sub>o</sub> - p <sub>T</sub> )10 <sup>3</sup> , heat capacity of 1/2 unit column	deg ly <sup>-1</sup>	7380 COMP 3
C0E1	(1) C0E*DTC3/24*3600, unit conversion factor for heating terms	deg day ly <sup>-1</sup>	7390 COMP 3
	(2) $\sigma_1 \pi \alpha_1 / 2T_1 + (c_p \theta_1 / 4T_1) \cdot [(p_3/p_o)^K - (p_1/p_o)^K]$ , level 1 geopotential parameter	m <sup>2</sup> sec <sup>-2</sup> deg <sup>-1</sup>	5360 COMP 2
C0E2	$\sigma_3 \pi \alpha_3 / 2T_3 + (c_p \theta_3 / 4T_3) \cdot [(p_3/p_o)^K - (p_1/p_o)^K]$ , level 1 geopotential parameter	m <sup>2</sup> sec <sup>-2</sup> deg <sup>-1</sup>	5370 COMP 2
C0E3	$\sigma_1 \pi \alpha_1 / 2T_1 - (c_p \theta_1 / 4T_1) \cdot [(p_3/p_o)^K - (p_1/p_o)^K]$ , level 3 geopotential parameter	m <sup>2</sup> sec <sup>-2</sup> deg <sup>-1</sup>	5400 COMP 2
C0E4	$\sigma_3 \pi \alpha_3 / 2T_3 - (c_p \theta_3 / 4T_3) \cdot [(p_3/p_o)^K - (p_1/p_o)^K]$ , level 3 geopotential parameter	m <sup>2</sup> sec <sup>-2</sup> deg <sup>-1</sup>	5410 COMP 2
C0LMR	(p <sub>o</sub> - p <sub>T</sub> )/(p <sub>s</sub> - p <sub>T</sub> ), column mass ratio (also redefined in 11530, COMP 3 with average p <sub>s</sub> - p <sub>T</sub> )	--	8060 COMP 3

FORTRAN Symbol	Meaning	Units	Program Location
CØNRAD	180/PI, unit conversion factor	deg/radian	7430 COMP 3
CØNV(J,I)	CØNVM, mass convergence at level 1	$\text{m}^2 \text{sec}^{-1} \text{mb}$	4220 COMP 1
CØNVM	$-(\text{mm}/2) \nabla \cdot \pi \vec{V}$ , net mass convergence into cell surrounding $\pi$ point (defined for poles in 4560, 4580 COMP 1)	$\text{m}^2 \text{sec}^{-1} \text{mb}$	4180-4210 COMP 1
CØNVP	$(h_4 - h_3^*) 5 \Delta t (\tau \tau_r)^{-1}$ , penetrating convection parameter	--	9300 COMP 3
CØSD	$\cos \zeta$ , cosine of solar declination	--	15540 SDET
CØSL(J)	$\cos \varphi_j$ , cosine of latitude	--	14960 INSDET
CØSZ	$\cos \zeta$ , cosine of solar zenith angle	--	7800 COMP 3
CPART	$0.5 * 1.3071 * 10^7$ , a constant (not used)	--	7690 COMP 3
CS	$10^2 c_D$ , unit conversion factor	$\text{cm m}^{-1}$	7990 COMP 3
CSEN	$C_r = 10^2 c_p c_D \rho_4 ( \vec{V}_s ^{\pi} + G)$ DAY, surface sensible heat flux parameter	$\text{ly day}^{-1} \text{deg}^{-1}$	9380 OMP 3
CS4	$10^2 c_p c_D$ DAY, surface sensible heat flux parameter	$\text{cm m}^{-1} \text{cal g}^{-1} \text{deg}^{-1} \text{sec day}^{-1}$	8000 COMP 3

FORTRAN Symbol	Meaning	Units	Program Location
CTI	thermal conductivity of ice (= 0.005)	ly sec <sup>-1</sup> cm deg <sup>-1</sup>	7320 COMP 3
CTID	thermal conductivity of ice (= 432)	ly day <sup>-1</sup> cm deg <sup>-1</sup>	7330 COMP 3
CXXX(800)	data control parameter (not used)	--	--
C1	$(\Delta T_1)_{CM} = (h_3 - h_1^*)(2 + \gamma_1)^{-1} 5\Delta t$ , level 1 temperature change due to mid-level convective latent heating	deg	8870 COMP 3
C1(800)	array identification	--	--
C3	$(\Delta T_3)_{CM} = (\Delta T_1)_{CM} (1 + \gamma_1)(LR/2)$ $[(h_3 - h_1^*) + (1 + \gamma_1)(LR/2)]^{-1}$ level-3 temperature change due to mid-level convective latent heating	deg	8880 COMP 3
DAY	hours in day (= 24), or sec in day (= 86,400)	hr, sec	13420, 13650 INPUT
DAYPYR	days in year (= 365)	day	13070 INPUT
DCLK	logical variable for day counter SDEDY	--	15050 INSDET
DEC	$(23.5\text{PI}/180)\cos[2\text{PI}(\text{DY}-173.0)/365]$ , solar declination	radians	15510 SDET
DECMAX	23.5PI/180, maximum solar declination	radians	13080 INPUT
DEFF	n = Δy, equatorial meridional mesh length	m	6880 AVRX



FORTTRAN Symbol	Meaning	Units	Program Location
DELTAP	correction for atmospheric mass loss (= PSF - ZMM)	mb	1430 GMP
DIRAD	$4\sigma T_g^3$ , long-wave radiation parameter at ground	$ly\ day^{-1}deg^{-1}$	10230 COMP 3
DIST	$(DY - 183.0)/365$ , day of year parameter	--	15450 SDET
DLAT	$\Delta\phi$ , north/south grid-point separation (= 4 deg) (changed to radians in 13590, INPUT)	deg	13360 INPUT
DLIC	input card identification (not used)	--	--
DLON	$\Delta\lambda = 2\pi/72$ , east/west grid-point separation (= 5 deg)	radians	13610 INPUT
DPLK	$p_3^K - p_1^K$	$(mb)^K$	8160 COMP 3
DQG	$B_e q_s(T_g) T_g^{-2} = \gamma_{gp} c/L$ , approximate change of $q_s$ with temperature, $\frac{dq_s(T_g)}{dT}$	$deg^{-1}$	9040 COMP 3
DRAT	n/m, grid scale ratio	--	6900 AVRX
DRAW	$C_D( \vec{V}_g ^{\pi} + G)$ , surface wind drag parameter	$m\ sec^{-1}$	8940 COMP 3
DR4	$4\sigma T_g^3(T_{gr} - T_g) = R_4 - \tilde{R}_4 = C_4$ , surface long-wave radiation parameter	$ly\ day^{-1}$	11160 COMP 3
DSIG	$\sigma_3 - \sigma_1$ , model sigma increment (= 1/2)	--	7250 COMP 3

FORTAN Symbol	Meaning	Units	Program Location
DT	$\Delta t$ in sec (= 360)	sec	13560 INPUT
DTC3	$5\Delta t$ , time interval between heating steps in COMP 3 (= 1800)	sec	7280 COMP 3
DTM	$\Delta t$ in min (= 6)	min	13340 INPUT
DXP(J)	$m = a\Delta\lambda \cos \varphi_j$ , east/west distance between $\pi$ (or $u^*$ ) points	m	14570 MAGFAC
DXU(J)	$m = a\Delta\lambda (\cos \varphi_j + \cos \varphi_{j-1})/2$ , east/west distance between $u, v$ (or $v^*$ ) points	m	14610 MAGFAC
DXV(J,I)	zonal distance between $\pi$ points (= DXP)	m	--
DXYP(J)	$mm$ , area of grid cell around $\pi$ point (defined for polar points in 14680, 14690 MAGFAC)	$m^2$	14670 MAGFAC
DY	$t$ , day counter (= SDEDY)	day	14530 SDET
DYP(J)	$n = (\varphi_{j+1} - \varphi_{j-1})a/2$ , north/south distance between $u, v$ (or $v^*$ ) grid points (defined for polar points in 14640, 14650 MAGFAC)	m	14630 MAGFAC
DYU(J)	$n = a(\varphi_j - \varphi_{j-1})$ , north/south distance between $\pi$ (or $u^*$ ) grid points	m	14540 MAGFAC
DYV(J,I)	meridional distance between $u, v$ points (= DYP)	m	--
ECCN	orbital eccentricity (= 0.0178)	--	13120 INPUT

FORTRAN Symbol	Meaning	Units	Program Location
ED	constant used in air/ground interaction (= 10.0)	m	13400 INPUT
EDR	$( \vec{V}_s ^{\pi}/2000) \left[  \vec{V}_s ^{\pi}/2000 + C_D ( \vec{V}_s ^{\pi} + G) \right]^{-1}$ , wind speed weighting factor	--	9060 COMP 3
EDV	$ \vec{V}_s ^{\pi}/2000$ , air/ground interaction parameter	m sec <sup>-1</sup>	8950 COMP 3
EFVC1	$u_{c1}^*$ , effective water vapor for type 1 clouds (= 65.3)	g cm <sup>-2</sup>	7660 COMP 3
EFVC2	$u_{c2}^*$ , effective water vapor for type 2 clouds (= 65.3)	g cm <sup>-2</sup>	7670 COMP 3
EFVC3	$u_{c3}^*$ , effective water vapor for type 3 clouds (= 7.6)	g cm <sup>-2</sup>	7680 COMP 3
EFVT	$u_T^* = p_3 q_3 g^{-1} (2 + K)^{-1} [(p_4/p_3)^{2+K} - (p_T/p_3)^{2+K}]$ , effective water vapor in air column below tropopause	g cm <sup>-2</sup>	9840 COMP 3
EFVO	$u_{\infty}^* = p_3 q_3 g^{-1} (2 + K)^{-1} [(p_4/p_3)^{2+K} - (120/p_3)^{2+K}]$ $+ 2.526 \times 10^{-5}$ , effective water vapor in entire atmospheric column	g cm <sup>-2</sup>	9850 COMP 3
EFV1	$u_1^* = p_3 q_3 g^{-1} (2 + K)^{-1} [(p_4/p_3)^{2+K} - (p_1/p_3)^{2+K}]$ , effective water vapor in air column below level 1	g cm <sup>-2</sup>	9830 COMP 3
EFV2	$u_2^* = p_3 q_3 g^{-1} (2 + K)^{-1} [(p_4/p_3)^{2+K} - (p_2/p_3)^{2+K}]$ , effective water vapor in air column below level 2	g cm <sup>-2</sup>	9820 COMP 3

FORTRAN Symbol	Meaning	Units	Program Location
EFV3	$u_3^* = p_3^2 q_3 g^{-1} (2 + K)^{-1} [(p_4/p_3)^{2+K} - 1],$ effective water vapor in air column below level 3	$g \text{ cm}^{-2}$	9810 COMP 3
EG	$e_s(T_g)$ , saturation vapor pressure at ground temperature	cb	9020 COMP 3
EQNX	equinox, 22 June (= 173.0)	day	13100 INPUT
ES1	$e_s(T_1)$ , saturation vapor pressure at level 1	cb	8350 COMP 3
ES3	$e_s(T_3)$ , saturation vapor pressure at level 3	cb	8360 COMP 3
ETA	entrainment factor (= 1)	--	9250 COMP 3
EVENT	program control parameter	--	--
EVNTH	data control parameter (not used)	--	--
EX	(1) $h_3 - h_1^* = HH3 - HH1S$ $= (L/c_p)[q_3 - q_s(T_1)] - L R c_p / L,$ stability parameter for middle-level convection (2) $h_4 - h_3^* = HH4 - HH3S,$ stability parameter for low-level convection	deg	8850 COMP 3
EXP1	empirical coefficient = 4/3	--	14780 MAGFAC
E4	$E = \rho_4 C_D ( \vec{V}_s ^n + G)(q_g - q_4)$ , surface evaporation rate	$g \text{ cm}^{-2} \text{ sec}^{-1}$	11240 COMP 3

FORTTRAN Symbol	Meaning	Units	Program Location
F(J)	$f = -2\Omega \partial(\cos \varphi_j)/\partial\varphi$ , Coriolis parameter (defined for poles in 14740-14750 MAGFAC)	$\text{sec}^{-1}$	14710-14730 MAGFAC
FAH	logical variable for temperature input	--	--
FAREN	identification for sea-surface temperature	--	--
FD(J,I)	(1) $\Pi = mn\pi$ , area-weighted pressure (about $\pi$ point)	$\text{m}^2\text{mb}$	2560 COMP 1
	(2) $V_s^2$ , square of surface wind speed	$\text{m}^2\text{sec}^{-2}$	7550 COMP 3
	(3) $F = mnf - u \partial m/\partial y$ , weighted Coriolis force (at $\pi$ -points)	$\text{m}^2\text{sec}^{-1}$	5070-5120 COMP 2
FDU	$\Pi^u$ = average $mn\pi$ at u,v points (defined for polar caps in 2650-2660 COMP 1)	$\text{m}^2\text{mb}$	2640 COMP 1
FEET	identification for topographic height	--	--
FIM	IM, maximum number of longitudinal grid points (= 72)	--	--
FIM1	I-1=i-1, longitudinal grid-point variable	--	--
FJ	J=j, longitudinal grid-point index	--	--
FJE	J index for equator (= $23\frac{1}{2}$ )	--	14460 MAGFAC
FJM	JM, maximum number of latitudinal grid points (= 46)	--	--
FK	$\rho_4 C_D g ( \vec{V}_s ^{\pi} + G)(\sigma_3 - \sigma_1)^{-1}(p_0 - p_T)^{-1}$ , surface friction parameter	$\text{sec}^{-1}$	11260 COMP 3

FORTAN Symbol	Meaning	Units	Program Location
FK1	$gC_D(\sigma_3 - \sigma_1)^{-1}(p_0 - p_T)^{-1}$ , surface friction parameter	$\text{cm}^2 \text{g}^{-1}$	8010 COMP 3
FL	$2\text{MOD}(K,2)+1$ , indicator for u,v data at levels 1 and 3	--	12350 COMP 4
FLUX	(1) $u^* \Delta t, v^* \Delta t$ , mass flux parameters	$\text{m}^2 \text{mb}$	3310, 3520 COMP 1
	(2) $-u^* \Delta t/4, -v^* \Delta t/4$ , mass flux parameters at level 1	$\text{m}^2 \text{mb}$	3390, 3610 COMP 1
	(3) $5u^* \Delta t/4, 5v^* \Delta t/4$ , mass flux parameters at level 3	$\text{m}^2 \text{mb}$	3610, 3620 COMP 1
	(4) various momentum flux parameters	$\text{m}^2 \text{mb}$	3830, 3910, 3980, 4050 COMP 1
FLUXQ	FLUX*Q3M (and other definitions), moisture flux parameters	$\text{m}^2 \text{mb}$	3480, 3660 COMP 1
FLUXT	FLUX*(T(J,I,L)+T(J,IP1,L)) (and other definitions), temperature advection parameters	$\text{m}^2 \text{mb deg}$	3320-3580 COMP 1
FLUXU	FLUX*(U(J,I,L)+U(J,IM1,L)) (and other definitions), u-momentum advection parameters	$\text{m}^2 \text{sec}^{-1} \text{mb}$	3840-4060 COMP 1
FLUXV	FLUX*(V(J,I,L)+V(J,IM1,L)) (and other definitions), v-momentum advection parameters	$\text{m}^2 \text{sec}^{-1} \text{mb}$	3870-4090 COMP 1
FM	$\text{FMX} \times 10^{-5}$ , a constant	--	13610 INPUT
FMX	constant (= 0.2)	--	13400 INPUT
FNM	NM, the integer part of DRAT	--	6940 AVRX

FORTRAN Symbol	Meaning	Units	Program Location
FSDEDY	t, day of year (= SDEDY)	day	7450 COMP 3
FS2	$S_2^A + CL \alpha_{c_1} (S_{CT_1}^A)''$ , total flux of $S_0^A$ at level 2 (plus reflected flux from type 1 cloud top)	ly day <sup>-1</sup>	10920 COMP 3
FS2C	(1) AS2T*CLT, clear sky flux at level 2, times type 2 or 3 cloudiness	ly day <sup>-1</sup>	10620, 10710 COMP 3
	(2) $CL \left[ (S_2^A)'' + \alpha_{c_1} (S_{CT_1}^A)'' \right]$ flux of $S_0^A$ at level 2 (plus flux reflected from cloud top) times type 1 cloudiness	ly day <sup>-1</sup>	10850 COMP 3
FS20	$(S_2^A)'$ , flux of $S_0^A$ at level 2 for clear sky	ly day <sup>-1</sup>	10550 COMP 3
FS4	$S_4^A + CL \alpha_{c_1} (S_{CT_1}^A)''$ , total flux of $S_0^A$ at level 4 (plus reflected flux from cloud top)	ly day <sup>-1</sup>	10930 COMP 3
FS4C	$CL \left[ (S_4^A)'' + \alpha_{c_1} (S_{CT_1}^A)'' \right]$ , flux of $S_0^A$ reaching level 4 (plus flux reflected from cloud top)	ly day <sup>-1</sup>	10640, 10740, 10870 COMP 3
FS40	$(S_4^A)'$ , flux of $S_0^A$ at level 4 for clear sky	ly day <sup>-1</sup>	10560 COMP 3
FXC0	(1) TEXC0/2, time-step factor for advection (other definitions in 3770, 5030 COMP 1)	sec	3270, 4710 COMP 1
	(2) DT/4, time-step factor for pressure force	sec	5470 COMP 2
	(3) $\Delta t/8c_p$ , time-step factor in thermodynamic energy equation	m <sup>-2</sup> sec <sup>3</sup> deg	6100 COMP 2

FORTTRAN Symbol	Meaning	Units	Program Location
FXC01	(1) $\text{TEXC0}/24$ , time-step factor for advection	sec	3780 COMP 1
	(2) $\text{DT}/2$ , time-step factor for pressure force	sec	5480 COMP 2
	(3) $\Delta t/4c_p$ , time-step factor in thermodynamic energy equation	$\text{m}^{-2}\text{sec}^3\text{deg}$	6110 COMP 2
F4	$\Gamma = C_r(T_g - T_4)$ , surface sensible heat flux	$\text{ly day}^{-1}$	11250 COMP 3
GAMG	$\gamma_g = (L/c_p)B_e q_s(T_g)T_g^{-2}$ , latent heat parameter	--	9080 COMP 3
GAM1	$\gamma_1 = (L/c_p)B_e q_s(T_1)T_1^{-2}$ , latent heat parameter	--	8420 COMP 3
GAM3	$\gamma_3 = (L/c_p)B_e q_s(T_3)T_3^{-2}$ , latent heat parameter	--	8430 COMP 3
GRAV	g, acceleration of gravity (= 9.81)	$\text{m sec}^{-2}$	13420 INPUT
GT(J,I)	$T_g$ , ground temperature (= $T_{gr}$ after radiation correction)	deg	11200 COMP 3
GW(J,I)	GW = WET, ground wetness ( $0 \leq \text{GW} \leq 1$ )	--	11360 COMP 3
GWM	ground water mass (= 30)	$\text{g cm}^{-2}$	7270 COMP 3
H(J,I,1)	(1) $(H1 + H3)/2$ , average heating	deg	11450 COMP 3
	(2) $(H1 + H3)mn/2$ , area-weighted average heating	$\text{deg m}^2$	11870 COMP 3
	[Note: H(J,I,2) not used.]		



FORTRAN Symbol	Meaning	Units	Program Location
HACØS	$\cos d \cos (t + \lambda)$ , solar zenith angle parameter	--	7780 COMP 3
HCST	unit conversion factor for surface elevation (= 1 if height in $10^2$ ft)	--	16200, 16260 INIT 2
HEIGHT(J)	surface height data	h ft, dm	16310 INIT 2
HHG	$T_g + (L/c_p)q_g$ WET, ground equivalent temperature	deg	9050 COMP 3
HH1S	$h_1^* = \theta_3(p_g/p_o)^K + (\theta_1 - \theta_3)(p_2/p_o)^K + (L/c_p)q_g(T_1)$ , level 1 stability parameter	deg	8790 COMP 3
HH3	$h_3 = \theta_3(p_g/p_o)^K + (L/c_p)q_3$ , level 3 stability parameter	deg	8770 COMP 3
HH3*	$h_3^* = \theta_3(p_g/p_o)^K + (L/c_p)q_g(T_3)$ , level 3 stability parameter	deg	8780 COMP 3
HH4	(1) $\tilde{h}_4$ , low-level temperature parameter	deg	9070 COMP 3
	(2) $h_4 = T_4 + (L/c_p)q_4$ , level 4 stability parameter	deg	9230 COMP 3
	(3) $h_3^*$ , level 3 stability parameter	deg	9252 COMP 3
HH4P	$h_4 = \text{HH4}$ , level 4 stability parameter	deg	9220 COMP 3
HICE	effective ice thickness (= 300)	cm	7340 COMP 3

FORTRAN Symbol	Meaning	Units	Program Location
HRGAS	R/2, one-half the dry air gas constant	$m^2 sec^{-2} deg^{-1}$	4990 COMP 2
HSCL	unit indicator for surface height	--	16240 INIT 2
H1	$H_1 = (A_1 + R_2 - R_0)(2g/\pi c_p)5\Delta t + (\Delta T_1)_{CM} + (\Delta T_1)_{CP}$ , total heating at level 1 (over $5\Delta t$ interval)	deg	11430 COMP 3
H3	$H_3 = (A_3 + R_4 - R_2 + \Gamma)(2g/\pi c_p)5\Delta t + (\Delta T_3)_{CM}$ $+ (\Delta T_3)_{CP} + (\Delta T_3)_{LS}$ , total heating at level 3 (over $5\Delta t$ interval)	deg	11440 COMP 3
I	i, longitude grid-point index (I = 1 is $\lambda = 0$ at 180 deg W)	--	--
IC(800)	integer array (= C)	--	--
ICE	ice-cover location indicator	--	7860 COMP 3
IC1(800)	array identification (alternate to C)	--	--
ICLOUD	cloud parameter (= 1 for clear, = 2 for partly cloudy, = 3 for overcast)	--	9430, 9710, 9720 COMP 3
ID	identification on input data card	--	--
IDAY	day number (= $TAU/ROTPER$ )	--	0500 CONTROL
IH	IM/2 + 1, longitudinal grid-point parameter (= 37)	--	--

FORTRAN Program	Meaning	Units	Program Location
IHALF(2)	two half words that form IWD	--	--
IL	(1) card identifier for topography	--	16320
	(2) left half word in packed data	--	INIT 2
	(3) index counter	--	--
ILEV	level identification parameter (not used)	--	--
ILH	entry point for left half word in IPKWD	--	--
IL1	temporary identification of topography cards	--	--
IL2		--	--
IL3		--	--
IM	maximum number of east/west grid points (= 72)	--	--
IMM2	IM - 2, longitudinal grid-point index	--	--
IM1	I - 1, longitudinal grid-point index	--	--
INU	identification for card reader input	--	--
IPKWD	pack data word (argument for ILH, IRH)	--	--
IP1	I + 1, longitudinal grid-point index	--	--
IR	right half word in packed data	--	--
IRH	entry point for right half word in IPKWD	--	--
ISINT	control parameter (not used)	--	--
IWD	word containing two half words	--	--

FORTRAN Symbol	Meaning	Units	Program Location
J	j, latitudinal grid-point index	--	--
JDYACC	variable for day of month determination	--	15350 SDET
JE	JM/2 + 1, latitudinal grid-point index (= 24)	--	6870 AVRX
JL	index counter	--	--
JM	maximum number of north/south grid points (= 46)	--	--
JMM1	JM - 1, latitudinal grid-point index	--	--
JMM2	JM - 2, latitudinal grid-point index	--	--
JTP	variable input/output identification (not used)	--	--
JUMP	control parameter (not used)	--	--
K	level or variable indicator (in friction calculation K = 1 or 2)	--	--
KAPA	$\kappa = R/c_p$ , thermodynamic ratio (= 0.286)	--	--
KEYS(J)	logical control parameters (not used)	--	--
KKK	packed data location in COMP 3	--	11690 COMP 3
KNT	variable input/output identification (not used)	--	--
KSET	array for KEY control characters (not used)	--	--
KTP	variable identification for history tape	--	--

FORTTRAN Symbol	Meaning	Units	Program Location
K1	2K, identifier for $u_1$ or $v_1$	--	11550 COMP 3
K2	2K + 1, identifier for $u_3$ or $v_3$	--	11560 COMP 3
L	level indicator (L = 1 for level 1, L = 2 for level 3)	--	--
LAND	land location indicator	--	7870 COMP 3
LAT(J)	$\varphi_j$ , latitude of grid point	radians	14490 MAGFAC
LDAY	t, day numbering origin (= 0)	day	15010 INSDET
LTP	variable input/output identification (not used)	--	--
LYR	year (if reset from input)	year	15040 INSDET
M	logical KEY function argument	--	--
MARK	MARK 1, control number in topography deck (= 0 if deck not read)	--	13680 INPUT
MAPGEN	map generation identification	--	--
MAPLST (3,40)	map list identification (not used)	--	--
MAXDAY	$\text{DAYPYR} + 10^{-2}$ , maximum allowed day in year (= 365.01)	day	15280 SDET

FORTRAN Symbol	Meaning	Units	Program Location
METER	identification for topographic height	--	--
MNTHDY	identification for day of month	day	--
M <del>ON</del> TH(12)	days in each month (beginning with January)	day	--
MRCH	identifier for steps in time integration (= 1, 2, 3, or 4)	--	1920, 2120-2140 STEP
MTP	variable identification for printed output	--	--
N	logical variable in KEYS array	--	--
NCYCLE	control parameter for MRCH (= 5)	--	13340 INPUT
NC3	number of time steps between uses of subroutine COMP 3 (= 5)	--	13340 INPUT
NM	integer part of DRAT	--	6930 AVRX
N <del>OO</del> UT	map generation output parameter	--	--
NP <del>O</del> L	zonal mean at north pole	(various)	--
NS	control parameter for time integration	--	2110 STEP
NSTEP	control parameter for time integration	--	0280 CONTROL
<del>O</del> CEAN	ocean location indicator	--	7850 COMP 3
<del>O</del> FF	solar declination control parameter	--	--

FORTRAN Symbol	Meaning	Units	Program Location
P(J,I)	$\pi = p_s - p_T$ , surface pressure parameter	mb	--
PASS2	data control parameter (not used)	--	--
PB1	(1) CONV(1,I), parameter for south pole mass convergence (2) QT(1,I,L), parameter for south pole calculations	$m^2 sec^{-1} mb$ (various)	4320-4410 COMP 1 6450-6500 COMP 2
PB2	(1) CONV(JM,I), parameter for north pole mass convergence (2) QT(JM,I,L), parameter for north pole calculations	$m^2 sec^{-1} mb$ (various)	4330-4420 COMP 1 6460-6510 COMP 2
PB3	PV(1,I), parameter for south pole mass convergence	$m^2 sec^{-1} mb$	4340-4430 COMP 1
PB4	PV(JM,I), parameter for north pole mass convergence	$m^2 sec^{-1} mb$	4350-4440 COMP 1
PC1	$(\Delta T_1)_{CP} = (h_4 - h_3^*) \tau_1 5\Delta t / \tau \tau_r$ , level 1 temperature change due to penetrating convection	deg	9310 COMP 3
PC3	$(\Delta T_3)_{CP} = (h_4 - h_3^*) \tau_2 5\Delta t / \tau \tau_r$ , level 3 temperature change due to penetrating convection	deg	9320 COMP 3
PHI(J,I)	(1) $\phi_1$ or $\phi_3$ , level 1 or 3 geopotential (2) $\sigma_1 \pi \alpha_1$ or $\sigma_3 \pi \alpha_3$ , pressure gradient parameter	$m^2 sec^{-2}$ $m^2 sec^{-2}$	5380, 5420 COMP 2 5760 COMP 2
PHI4	$\phi_4 = VPHI4(J,I)$ , surface geopotential (= 0 if ocean)	$m^2 sec^{-2}$	5300 COMP 2

FORTRAN Symbol	Meaning	Units	Program Location
PI	constant $\pi = 3.1415926$	--	13040 INPUT
PIT(J,I)	$-(\pi/2) [\nabla \cdot \pi (\vec{V}_1 + \vec{V}_3)] = \text{CONV}(J,I) + \text{PV}(J,I)$ , net column mass convergence (= $\pi$ tendency)	$\text{m}^2 \text{sec}^{-1} \text{mb}$	4520 COMP 1
PK1	$p_1^\kappa$ , upper-level pressure to kappa power	$(\text{mb})^\kappa$	4600 COMP 1
PK3	$p_3^\kappa$ , lower-level pressure to kappa power	$(\text{mb})^\kappa$	4610 COMP 1
PL1	$p_1 = p_T + \sigma_1 \pi$ , level 1 pressure	mb	4580 COMP 1
PL1K	$p_1^\kappa$ , upper-level pressure to kappa power	$(\text{mb})^\kappa$	8120 COMP 3
PL2	$p_2 = p_T + \pi/2$ , level 2 pressure	mb	8100 COMP 3
PL2K	$p_2^\kappa$ , middle-level pressure to kappa power	$(\text{mb})^\kappa$	8140 COMP 3
PL3	$p_3 = p_T + \sigma_3 \pi$ , level 3 pressure	mb	4590 COMP 1
PL3K	$p_3^\kappa$ , lower-level pressure to kappa power	$(\text{mb})^\kappa$	8130 COMP 3
PM	$p_0 - p_T$ , standard tropospheric pressure depth (= 800)	mb	7370 COMP 3
PREC	$(\Delta q)_{LS} = [q_3 - q_s(T_3)] \cdot [1 + (L/c_p) B_e q_s(T_3) T_3^{-2}]^{-1}$ , level 3 moisture change due to large-scale condensation	--	8650 COMP 3



FORTRAN Symbol	Meaning	Units	Location
PSF	reference global mean surface pressure (= 984)	mb	1430 CMP, 13480 INPUT
PSL	$p_o$ , reference sea-level pressure (= 1000)	mb	13460 INPUT
PT(J,I)	$\pi + \Delta t \text{ PIT}/\text{mn}$ , updated $\pi$ value	mb	4540 COMP 1
PTRK	$p_T^k$	(mb) <sup>k</sup>	8150 COMP 3
PTRØP	$p_T$ , tropopause pressure (= 200)	mb	13460 INPUT
PU(J,I)	(1) $u^* = \text{mn}u$ , zonal mass flux (at $u^*$ points)	$\text{m}^2 \text{sec}^{-1} \text{mb}$	2780-2890 COMP 1
	(2) TEMP 1, provisional pressure gradient parameter	$\text{m}^2 \text{sec}^{-2} \text{mb}$	5560 COMP 2
	(3) TEMP, provisional term in energy equation (other provisional definition in 6270 COMP 2, 12320 COMP 4)	$\text{sec}^2 \text{deg}$	6190 COMP 2
PV(J,I)	(1) $v^* = \text{mn}v$ , meridional mass flux (at $v^*$ points)	$\text{m}^2 \text{sec}^{-1} \text{mb}$	2910-2940 COMP 1
	(2) CONVM, mass convergence at level 2	$\text{m}^2 \text{sec}^{-1} \text{mb}$	4230 COMP 1
	(3) polar PU equivalent (various definitions) (other definitions in COMP 4)	$\text{m}^2 \text{sec}^{-1} \text{mb}$	3050-3170 COMP 1
PLCB	$p_1/10$ , level 1 pressure in centibars	cb	8370 COMP 3
P1OK	$p_o^k$	(mb) <sup>k</sup>	7310 COMP 3

FORTRAN Symbol	Meaning	Units	Program Location
P3CB	$p_3/10$ , level 3 pressure in centibars	cb	8380 COMP 3
P4	$p_4 = p_s = \pi + p_T$ , surface pressure	mb	8070 COMP 3
P4CB	$p_4/10$ , surface pressure in centibars	cb	8390 COMP 3
P4K	$p_4^K$	(mb) <sup>K</sup>	8080 COMP 3
Q(J,I,K)	equivalence array (K = 1, 2, ... 9; see Chapter VII, Subsection A.3)	(various)	2060 STEP
QD(J,I,9)	array identification (alternate to QT)	--	--
QG	$q_s(T_g)$ , ground-level saturation mixing ratio	--	9030 COMP 3
QN	$\Delta q_3$ , total level 3 mixing ratio change due to convection, condensation, evaporation	--	11300 COMP 3
QS1	$q_s(T_1)$ , level 1 saturation mixing ratio	--	8400 COMP 3
QS3	$q_s(T_3)$ , level 3 saturation mixing ratio	--	8410 COMP 3
QT(J,I,K)	equivalence array for temporary variables (K = 1, 2, ... 8; see Chapter VII, Subsection A.3)	(various)	2070 STEP
QTOT (J,I,20)	equivalence array (see Chapter VII, Subsection A.3)	(various)	0140 COMMON

FORTRAN Symbol	Meaning	Units	Program Location
Q3(J,I)	$q_3$ , level 3 mixing ratio	--	--
Q3M	level 3 moisture parameter	--	3410, 3660 COMP 1
Q3R	$q_3 - (\Delta q_3)_{LS}$ , level 3 mixing ratio after large-scale condensation	--	8680 CCOMP 3
Q3RB	$\max(q_3, 10^{-5})$ , provision to insure $q_3 \geq 10^{-5}$	--	9770 COMP 3
Q3T(J,I)	$q_3^H$ , pressure-area-weighted level 3 mixing ratio (also moisture flux at 3710, 3720 COMP 1)	$m^2 mb$	2570 COMP 1
Q4	(1) $RH_4[q_g(T_g) + (c_p/L)\gamma_g(T_4 - T_g)]$ , level 4 moisture parameter	--	9110 COMP 3
	(2) $q_4 = q_g(T_3) + [\theta_3(p_g/p_o)^K - T_4](c_p/L)$ , level 4 mixing ratio	--	9350 COMP 3
RAD	a, earth's radius (= 6375) (redefined in m in 13640, INPUT)	km	13420 INPUT
RCNV	$DTC3/TCNV, = 5\Delta t/\tau_r = 1/2$	hr	7290 COMP 3
RESET	day and year control parameter	--	--
RGAS	R, gas constant for dry air (= 287)	$m^2 deg^{-1} sec^{-2}$	13440 INPUT
RH3	$RH_3 = q_3/q_g(T_3)$ , relative humidity at level 3	--	8450 COMP 3

FORTRAN Symbol	Meaning	Units	Program Location
RH4	$RH_4 = 2RH_3 \cdot GW(RH_3 + GW)^{-1}$ , ground-level humidity measure	--	9000 COMP 3
ROT	$t = t \cdot 2\pi/24$ hr, hour of day (converted to radians)	radians	7700 COMP 3
ROTPER	period of solar rotation (= 24.0)	hr	13090 INPUT
R04	$\rho_4 = p_s(RT_4)^{-1}$ , air density at level 4 (surface)	$g\ cm^{-3}$	9370 COMP 3
RSDIST	square of the normalized earth/sun distance	--	15520 SDET
RSETSW	input identification	--	--
RUNOFF	WET/2, fraction of rainfall which runs off	--	11340 COMP 3
R0	(1) $\tilde{R}_O$ , long-wave radiation parameter at tropopause	$ly\ day^{-1}$	10200 COMP 3
	(2) $R_O = \tilde{R}_O + 0.8(1 - CL)(R_4 - \tilde{R}_4) \cdot \tau(u_O^*)$ , net upward long-wave radiative flux at tropopause	$ly\ day^{-1}$	11190 COMP 3
ROC	$R_O^{CL}$ , cloudy sky part of long-wave radiative flux at tropopause, times cloudiness (separately defined for cloud types 1, 2, 3)	$ly\ day^{-1}$	10040, 10100, 10170 COMP 3
R00	$R_O'$ , clear sky part of long-wave radiative flux at tropopause	$ly\ day^{-1}$	9980 COMP 3

FORTRAN Symbol	Meaning	Units	Program Location
R2	(1) $\tilde{R}_2$ , long-wave radiation parameter at level 2  (2) $R_2 = \tilde{R}_2 + 0.8(1 - CL)(R_4 - \tilde{R}_4) \cdot \tau(u_2^*)$ , net upward long-wave radiative flux at level 2	ly day <sup>-1</sup>  ly day <sup>-1</sup>	10210 COMP 3  11180 COMP 3
R2C	$R_2^{CL}$ , cloudy sky long-wave radiative flux at level 2, times cloudiness (separately defined for cloud types 1, 2, 3)	ly day <sup>-1</sup>	10050, 10010, 10180 COMP 3
R20	$R_2'$ , clear sky part of long-wave radiative flux at level 2	ly day <sup>-1</sup>	9990 COMP 3
R4	(1) $\tilde{R}_4$ , long-wave radiation parameter at level 4  (2) $R_4 = \tilde{R}_4 + \sigma T_g^3(T_{gr} - T_g)$ , net upward long- wave radiative flux at level 4 (surface)	ly day <sup>-1</sup>  ly day <sup>-1</sup>	10220 COMP 3  11170 COMP 3
R4C	$R_4^{CL}$ , cloudy sky long-wave radiative flux at level 4 (ground), times cloudiness	ly day <sup>-1</sup>	10190 COMP 3
R40	$R_4'$ , clear sky part of long-wave radiative flux at level 4 (ground)	ly day <sup>-1</sup>	10000 COMP 3
SA	$S_O^A \sim 0.349 S_O \cos \zeta$ , part of incoming solar radiation subject to absorption	ly day <sup>-1</sup>	10460 COMP 3
SCALE	scale factor for layer radiative heating	deg ly <sup>-1</sup>	11680 COMP 3
SCALEP	scale factor for layer latent heating	mm day <sup>-1</sup> mb <sup>-1</sup>	7420 COMP 3

FORTRAN Symbol	Meaning	Units	Program Location
SCALEU	$(10/c_p)(2g/\pi)$ , scale factor for column heat capacity	$\text{deg ly}^{-1}$	7400 COMP 3
SC0SZ	$S_0 \cos \zeta$ , total solar radiation at top of atmosphere	$\text{ly day}^{-1}$	10280 COMP 3
SD(J,I)	$(\Delta m/2)[\nabla \cdot \pi(\vec{V}_3 - \vec{V}_1)] = \text{CONV}(J,I) - \text{PV}(J,I)$ , net mass convergence ( $= \dot{S} = 2\Delta m \pi \dot{\sigma}$ )	$\text{m}^2 \text{sec}^{-1} \text{mb}$	4530 COMP 1
SDEY	day counter starting from origin LDAY	day	15030 INSDET
SDU	$\dot{S}^u$ , four-point average mass convergence	$\text{m}^3 \text{sec}^{-2} \text{mb}$	4750 COMP 1
SEASON	(DY-173.0)/365, time parameter in solar declination	--	15440 SDET
SIG1	$\sigma_1$ , upper-level $\sigma$ value ( $= 1/4$ )	--	7230 COMP 3
SIG3	$\sigma_3$ , lower-level $\sigma$ value ( $= 3/4$ )	--	7240 COMP 3
SIGC0	FL/2, level designator	--	12360 COMP 4
SIND	$\sin \zeta$ , sine of solar declination	--	15530 SDET
SINL(J)	$\sin \varphi_j$ , sine of latitude	--	14950 INSDET
SINT	control parameter (not used)	--	--

FORTRAN Symbol	Meaning	Units	Program Location
SN(J,I)	identification for VT(1,1,2)	--	--
SNØW	designator for snow-covered land	--	7880 COMP 3
SNØWN	snowline in northern hemisphere (varies $\pm 15^\circ$ about 60 deg N)	radians	7460 COMP 3
SNØWS	snowline in southern hemisphere (= 60 deg S)	radians	7470 COMP 3
SP	$P(J,I) = \pi$ , surface pressure parameter	mb	8050 COMP 3
SPØL	zonal mean at south pole	(various)	--
SS	$S_o^S = 0.651 S_o \cos \zeta$ , part of incoming solar radiation subject to scattering	ly day <sup>-1</sup>	10470 COMP 3
SS1	$\theta_3(p_s/p_o)^K + (\theta_1 - \theta_3)(p_2/p_o)^K$ , convective stability parameter	deg	8760 COMP 3
SS2	$\theta_3(p_s/p_o)^K + \frac{1}{2} (\theta_1 - \theta_3)(p_2/p_o)^K$ , convective stability parameter	deg	8750 COMP 3
SS3	$\theta_3(p_s/p_o)^K$ , convective stability parameter	deg	8740 COMP 3
STAGI	logical variable for zonal map staggering	--	--
STAGJ	logical variable for meridional map staggering	--	--
STBØ	$\sigma$ , Stefan-Boltzman constant	ly day <sup>-1</sup> deg <sup>-4</sup>	7650 COMP 3

FORTRAN Symbol	Meaning	Units	Program Location
S0	$S_0$ , solar constant (modified for earth/sun distance)	ly day <sup>-1</sup>	7610 COMP 3
S4	$S_g = (1 - CL)S'_g + CL S''_g$ , total flux of short-wave radiation absorbed by the ground	ly day <sup>-1</sup>	10940 COMP 3
S4C	$S''_g$ , cloudy sky part of short-wave radiation absorbed by the ground (defined separately for cloud types 1, 2, 3)	ly day <sup>-1</sup>	10660, 10760, 10890 COMP 3
S40	$S'_g$ , clear sky part of short-wave radiation absorbed by the ground	ly day <sup>-1</sup>	10570 COMP 3
T(J,I,L)	level 1 or level 3 temperature (also for temperature after heating and smoothing in 11470, 11980, COMP 3); L = 1 denotes $T_1$ , L = 2 denotes $T_3$	deg	8280 COMP 3
TAU	time in hr	hr	--
TAUC	input identification (not used)	--	--
TAUD	frequency of recalculation of solar declination (= 24)	hr	13310 INPUT
TAUE	day of integration end	day, hr	13310, 13320 INPUT
TAUH	frequency of history tape storage (= 6)	hr	13310 INPUT
TAUI	TAUID · 24 + TAUH, starting time (in hr)	hr	13290 INPUT
TAUID	starting time	day	13730 INPUT



FORTRAN Symbol	Meaning	Units	Program Location
TAUIH	hour of starting time	hr	13740 INPUT
TAUØ	output interval (= 24)	hr	13310 INPUT
TAUX	starting time parameter	hr	13700 INPUT
TBAR	$(T_1 + T_3)/2$ , average temperature	deg	12830 COMP 4
TCNV	relaxation time for cumulus convection (= 3600)	sec	13400 INPUT
TD(J,I)	$(T_3 - T_1)/2\pi$ , vertical temperature (lapse-rate) parameter	deg mb <sup>-1</sup>	12740 COMP 4
TDBAR	smoothed value of TD	deg mb <sup>-1</sup>	12790 COMP 4
TDSM	weighted TD parameter	deg	12820 COMP 4
TEM	$\tilde{B}$ , conduction coefficient for ice (also defined as cloudiness parameters in COMP 3 but not used)	ly day <sup>-1</sup> deg <sup>-1</sup>	11080 COMP 3
TEMB	short-wave radiative flux reflected from type 1 cloud top	ly day <sup>-1</sup>	10840 COMP 3
TEMP	(1) intermediate parameter in thermodynamic energy conversion calculation	sec <sup>2</sup> deg	6160-6340 COMP 2
	(2) $\tau$ , penetrating convection parameter	deg	9280 COMP 3
	(3) $(H1 - H3)/2$ , heating parameter	deg	11460 COMP 3

FORTTRAN Symbol	Meaning	Units	Program Location
TEMP	(4) vertical wind shear ( $u_1 - u_3$ or $v_1 - v_3$ ) (5) $\bar{H}^A$ , averaged heating	$m \text{ sec}^{-1}$ deg	11570 COMP 3 11930-11950 COMP 3
TEMP1	(1) intermediate parameter in pressure gradient calculation (2) $\tau_1 = (h_3^* - h_1^*)(1 + \gamma_1)^{-1} + LR/2$ , penetrating convection parameter	$m^2 \text{ sec}^{-2} \text{ mb}$ deg	5550, 5810 COMP 2 9260 COMP 3
TEMP2	(1) intermediate parameter in pressure gradient calculation (2) $\tau_2 = \theta_3(p_4/p_0)^K - T_4 + LR/2$ , penetrating convection parameter	$m^3 \text{ sec}^{-2} \text{ mb}$ deg	5570, 5830 COMP 2 9270 COMP 3
TEMS	$(S_4^A)''$ , flux of $S_0^A$ reaching level 4 through clouds (defined separately for cloud types 1, 2, 3)	$ly \text{ day}^{-1}$	10630, 10730, 10860 COMP 3
TEMSCL	sea-surface temperature unit indicator	--	15910 INIT 2
TEMU	$(u_\infty^* - u_1^* \text{ or } u_3^*) \text{ sec } \zeta$ , parameter for transmission of $S_0^A$ through type 1 or type 3 clouds	$g \text{ cm}^{-2}$	10720, 10830 COMP 3
TEM1	$p_3^2 q_3 (2 + K)^{-1} g^{-1}$ , water vapor parameter	$g \text{ cm}^{-2}$	9790 COMP 3
TEM2	$p_3^2 q_3 (2 + K)^{-1} g^{-1} (p_4/p_3)^{2+K}$ , water vapor parameter	$g \text{ cm}^{-2}$	9800 COMP 3
TETAM	$\theta_2 p_0^{-K}$ , temperature parameter	$\text{deg mb}^{-K}$	4620 COMP 1

FORTRAN Symbol	Meaning	Units	Program Location
TETA1	$\theta_1$ , level 1 potential temperature	deg K	8720 COMP 3
TETA3	$\theta_3$ , level 3 potential temperature	deg K	8730 COMP 3
TEXCO	DT, time step (= 360) (also defined as DT/2 in 2480 COMP 1, 4970 COMP 2 for advective terms)	sec	2470 COMP 1 4960 COMP 2
TG	$T_g$ , ground temperature (original)	deg K	8560 COMP 3
TGR	(1) $T_{gr} = T_g$ if ocean, $T_{gr} = T_o$ if ice or snow and $T_{gr} > T_o$	deg K	11040 COMP 3
	(2) $T_{gr} = (A1 + A2)/(B1 + B2)$ , ground temperature (revised)	deg K	11130 COMP 3
TG00	<del>TOP</del> OG, ocean surface temperature or surface geopotential	deg or $m^2 sec^{-2}$	7840 COMP 3
THL1	$\theta_1 p_o^{-K}$ , level 1 temperature parameter	deg $mb^{-K}$	8220 COMP 3
THL3	$\theta_3 p_o^{-K}$ , level 3 temperature parameter	deg $mb^{-K}$	8230 COMP 3
THRP	time in days and fractions (= TAU/24)	day	1970 STEP
TICE	$T_o$ , melting point of ice (= 273.1)	deg K	7350 COMP 3
TØFDAY	t = time of day counter (Greenwich hours)	hr	14120 INPUT

FORTRAN Symbol	Meaning	Units	Program Location
TOPOG(J,I)	surface topography indicator	deg or m <sup>2</sup> sec <sup>-2</sup>	16090 INIT 2
TRANS(X)	$\tau(x) = (1 + 1.75x^{0.416})^{-1}$ , slab transmission function for long-wave radiation ( $x = u_n^*$ in g cm <sup>-2</sup> )	--	7150 COMP 3
TREADY	integration control parameter (not used)	--	--
TRST	tape output control parameter	--	--
TRSW(X)	$1 - 0.271x^{0.303}$ , transmission function for short-wave radiation ( $x = u_n^*$ in g cm <sup>-2</sup> )	--	7160 COMP 3
TS(J,I)	identification for UT(1,1,2)	--	--
TSPD	DAY/DTC3, number of source (COMP 3) calculations per day (= 48)	--	7410 COMP 3
TT(J,I,L)	(1) T, temperature	deg K	1960 STEP
	(2) T <sub>W</sub> , pressure-area-weighted temperature	m <sup>2</sup> deg mb	2620 COMP 1
TTRØP	T <sub>T</sub> or T <sub>0</sub> , tropopause temperature (extrapolated from T <sub>1</sub> and T <sub>3</sub> in p <sup>K</sup> space	deg K	8510 COMP 3
T1	T <sub>1</sub> , level 1 temperature (redefined if convective adjustment occurs)	deg K	8200, 8280 COMP 3
T2	T <sub>2</sub> , level 2 temperature	deg K	8520 COMP 3

FORTRAN Symbol	Meaning	Units	Program Location
T3	$T_3$ , level 3 temperature (redefined if convective adjustment or large-scale condensation occurs in 8660, COMP 3)	deg K	8210, 8270 COMP 3
T4	$T_4$ , air temperature at level 4 (redefined if convection occurs in 9340, COMP 3)	deg K	9090 COMP 3
U(J,I,L)	$u$ , zonal wind speed (L = 1 designates $u_1$ , L = 2 designates $u_3$ )	$m \text{ sec}^{-1}$	--
URT	$\sigma T_T^4 (u_\infty^* - u_T^*)$ , total long-wave flux at tropopause from atmosphere above tropopause	$ly \text{ day}^{-1}$	9950 COMP 3
UR2	$\sigma T_2^4 (u_\infty^* - u_2^*)$ , total long-wave flux at level 2 from atmosphere above level 2	$ly \text{ day}^{-1}$	9960 COMP 3
US	$u_s = 0.7(3u_3 - u_1)/2$ , surface zonal wind speed	$m \text{ sec}^{-1}$	7530 COMP 3
UT(1,I,1)	provisional variable during zonal smoothing	---	7000 AVRX
UT(J,1,L)	(1) $u\pi^u$ , pressure-area-weighted zonal wind speed (2) $u\pi$ , value after Coriolis force calculation	$m^3 \text{ mb sec}^{-1}$ $m^3 \text{ mb sec}^{-1}$	2670 COMP 1 3170 COMP 2
V(J,I,L)	$v$ , meridional wind speed (L = 1 designates $v_1$ , L = 2 designates $v_3$ )	$m \text{ sec}^{-1}$	--
VAD	TEXCO $\dot{S}^u_{u_2, v_2}/2$ , vertical advection of $u, v$ momentum	$m^3 \text{ sec}^{-1} \text{ mb}$	4780, 4810 COMP 1

FORTRAN Symbol	Meaning	Units	Program Location
VAK	$2 + K$ , parameter for effective water amount	--	9780 COMP 3
VIVA	data control parameter (not used)	--	--
VKEYV	name of labeled common block (KEYS)	--	--
VM1	polar mass flux parameters (various definitions)	--	2990-3120 COMP 1
VM2	polar mass flux parameters (various definitions)	--	3000-3210 COMP 1
VPHI4(J,I)	$\phi_4$ , surface (level 4) geopotential (* 0 if ocean)	$m^2 sec^{-2}$	1570 VPHI4
VPK1	$(p_1/p_3)^K$ , level 1 geopotential parameter	--	5330 COMP 2
VPK3	$(p_3/p_1)^K$ , level 3 geopotential parameter	--	5340 COMP 2
VPS1	$\sigma_1 \pi / p_1$ , level 1 pressure gradient parameter	--	5310 COMP 2
VPS3	$\sigma_3 \pi / p_3$ , level 3 pressure gradient parameter	--	5320 COMP 2
VS	$v_s = 0.7(3v_3 - v_1)/2$ , surface meridional wind speed	$m sec^{-1}$	7540 COMP 3
VT(J,I,L)	(1) $v\pi^u$ , pressure-area-weighted meridional wind speed	$m^3 sec^{-1} mb$	2680 COMP 1
	(2) $v\pi$ , value after Coriolis force calculation	$m^3 sec^{-1} mb$	5190 COMP 2

FORTRAN Symbol	Meaning	Units	Program Location
W(J,I)	temporary variable for H, PV, PHI, QT	(various)	--
WET	GW, ground wetness (scaled 0 to 1)	--	11360 COMP 3
WINDF	$ \vec{V}_s ^n + G$ , surface wind speed with gustiness correction ( $G = 2.0 \text{ m sec}^{-1}$ )	$\text{m sec}^{-1}$	8930 COMP 3
WMAG	$ \vec{V}_s ^n$ , surface wind speed (root-mean-square value)	$\text{m sec}^{-1}$	7940-7950 COMP 3
WMAGJH	$ \vec{V}_s ^n$ , surface wind speed for north pole	$\text{m sec}^{-1}$	7570 COMP 3
WMAGI	$ \vec{V}_s ^n$ , surface wind speed for south pole	$\text{m sec}^{-1}$	7560 COMP 3
WORK1(J,I) } WORK2(J,I) }	temporary array in map routines	(various)	1760 MAPGEN
WTM	$ mn $ , area weighting factor magnitude	$\text{m}^2$	1370, 1400 CMP
WW	$2\pi n \dot{\phi}$ , vertical velocity measure	$\text{m}^2 \text{ mb hr}^{-1}$	11670 COMP 3
XLABL(9)	input character identification	--	--
XLEV	level identification parameter (not used)	--	--
XX1	$(T_1 + T_3)/(p_1^K + p_3^K)$ , convective adjustment parameter	$\text{deg mb}^{-K}$	8250 COMP 3

FORTRAN Symbol	Meaning	Units	Program Location
XXX	packed data location (= KKK)	--	11700 COMP 3
ZL3	average height of level 3 (= 2000)	m	8920 COMP 3
ZM(J)	zonal mean at latitude $\varphi_j$	(various)	1360 GMP
ZMM	global mean	(various)	1420 GMP
ZMONTH(3,12)	names of months	--	--
ZZZ	$\phi_s/g$ , height of surface (level 4) (= 0 if ocean)	m	7900 COMP 3



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